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SIXTH ANNUAL CONVENTION

AMERICAN SOCIETY FOR QUALITY CONTROL

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FOREWORD

The excellent cooperation of the authors in meeting an early deadline and in presenting their manuscripts in suitable form for direct reproduction has made this publication possible.

Although every effort was made to make these transactions as complete as possible, a few papers were not received in time for publication. These may appear in the Society's magazine "Industrial Quality Control" in the near future.

George M. Armour
Chairman, Transactions Committee

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A. GENERAL INTEREST

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SPECIAL APPLICATIONS FOR QUALITY CONTROL CHARTS

Wyatt H. Lewis
General Electric Company

Over the past several years literally hundreds of quality control operators have attested to the fact that the Shewhart quality control chart does work. Speeches, papers, magazine articles and books have been used to reveal this remarkable device to American Industry.

It has been proven that the control chart obeys the laws of mathematical probability and will detect the presence of assignable causes operating on the process. It will also tell <u>when</u> these assignable causes are operating so the quality control investigator can sally forth at the right time in an endeavor to identify the cause or causes and answer the other questions of who, what, where and why. The latter job is detective work that the control chart will not do by itself. This is up to the quality control engineer or persons assisting him.

Let us say then without further argument that the control chart does quite well the job expected of it—namely, telling when assignable causes of variation are operating. Not many quality control men would want to debate that statement. There is, however, a large field open for debate on the manner in which quality control charts are applied. Aside from such matters as frequency of sample, size of sample, nature of sub-grouping, etc., there are the following questions that might evoke a lively discussion among quality control personnel.

1. Are control charts for averages too confusing for use of shop operators? (They are accustomed to thinking in terms of measurement and specification for individual items.)

2. Should control charts be reserved for use in the engineering laboratory?

3. How many quality characteristics on how many items should be charted?

4. To what extent should control charts be routinized?

5. What use can be made of the quality control chart in special investigations of short duration?

These are just a few of the questions that can arise in trying to apply control charts. Furthermore they are questions that have to be answered to permit successful day by day operation of a quality control program.

In any discussion among quality control supervisors and engineers is heard the expression, "Now this is the way we do it." Swapping of ideas and methods is valuable and that is the primary purpose of any convention such as this one we are attending.

I'll tell you how we do it, but first let me acquaint you with our type of operation. The Ontario (California) Plant of the General Electric Company manufactures automatic flatirons and steam irons. It is almost completely integrated. The calrod heating element is manufactured at Ontario and cast into a soleplate—either aluminum or castiron. The soleplates leave the foundry and go over an automatic machining line. After machining, the soleplates are polished and buffed. In the case of castiron a protec-

FF-762-8 (8-45)
(Formerly GO-1468-8)

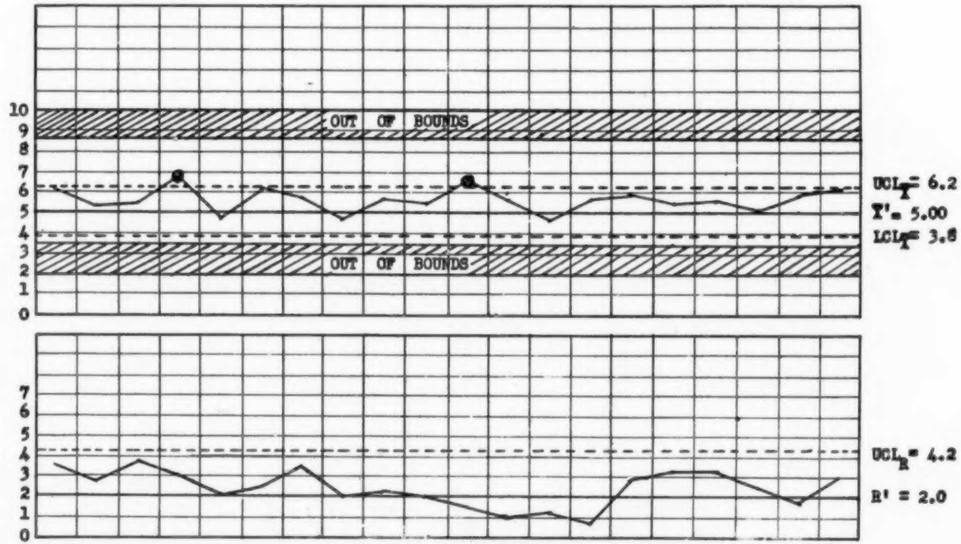
QUALITY CONTROL CHART NUMBER 1

Product 5718933-4 Thermostat

Period Oct. 5 - Oct. 26, 1951

Inspection or Test Rocker Arm Pressure at Max. Temp Setting

Characteristic Ounces (Spec. 2.0 to 10.0)



Sample		9am	1pm	7am	9am	11am	2am	9am	3pm	7am	9pm	10pm	2pm	9pm	9am	11am	2pm	7am	9am	11am	2pm
Measurement	1	6.75	5.50	4.75	9.25	4.25	5.25	6.25	5.25	5.75	4.75	7.50	5.75	4.25	5.75	4.50	6.75	8.00	4.25	6.25	4.50
	2	4.00	5.50	3.50	5.75	6.00	5.75	6.75	5.00	5.00	5.50	6.00	6.00	4.50	6.00	6.25	4.25	4.75	5.50	6.25	6.00
	3	7.50	5.75	7.25	6.00	4.75	7.75	6.75	3.25	7.00	5.00	7.25	5.75	4.25	5.25	7.25	5.25	5.25	6.50	6.00	7.50
	4	7.25	6.25	5.50	6.75	4.00	6.75	5.75	5.25	4.75	6.00	6.00	5.00	4.75	5.75	5.00	7.00	5.75	4.00	4.50	6.50
	5	5.25	3.50	6.50	6.50	4.50	5.25	3.25	4.50	6.25	6.75	6.25	5.50	5.50	5.25	6.50	3.75	3.75	5.00	6.25	6.00
Totals		30.75	26.50	27.50	34.25	23.50	30.75	28.75	23.25	28.75	28.00	33.00	28.00	23.25	28.00	29.50	27.00	27.50	25.25	29.25	30.50
X̄		6.15	5.30	5.50	6.85	4.70	6.15	5.75	4.65	5.75	5.60	6.60	5.60	4.65	5.60	5.90	5.40	5.50	5.05	5.85	6.10
R		3.50	2.75	3.75	3.50	2.00	2.50	3.50	2.00	2.25	2.00	1.50	1.00	1.25	.75	2.75	3.25	3.25	2.50	1.75	3.00
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tive and decorative plate of nickel and chromium is used. We also mold handles for the irons in our Plastics Section. Tops are blanked and drawn in our Press Section. These are finished and plated, ready for assembly. The Press Section also stamps out small parts used in fabrication of the thermostat and tank for the steam iron. Heater cord is purchased in reels, cut to length and prepared for assembly with plug and connections. All these various components are brought together on an assembly conveyor. The completed irons are then run over an energized conveyor where they are heated and tested. The irons are then buffed, given a final visual inspection and packed for shipment.

Perhaps the first thing you would notice upon taking a quality control tour through our factory would be the lack of $\bar{X}$, R Charts at the location of the operation. These are several reasons for this: first, we have no screw machine section. All screw machine parts are purchased. In the second place our machining operations are highly standardized, in-line operations. Through years of experience, cutter life has been determined and cutters are changed after so many thousand pieces run. Initial check on set-up has been found adequate; hence, control charts in this section would not pay their way.

We do have several $\bar{X}$, R Charts in the factory such as calrod winding resistance, calrod tubing diameter, straightness and length. Calrod wattage is also plotted on a control sample although all units are 100% inspected automatically on a test machine. A few special machining operations also use conventional $\bar{X}$, R Charts such as the location of the filler tube hole in the steam tank riser tube.

The Thermostat Assembly Section has provided the best field for applying $\bar{X}$, R Charts for routine control purposes. Commonplace applications include strengths of welds for contacts to contact springs, bimetal assembly welds, etc.

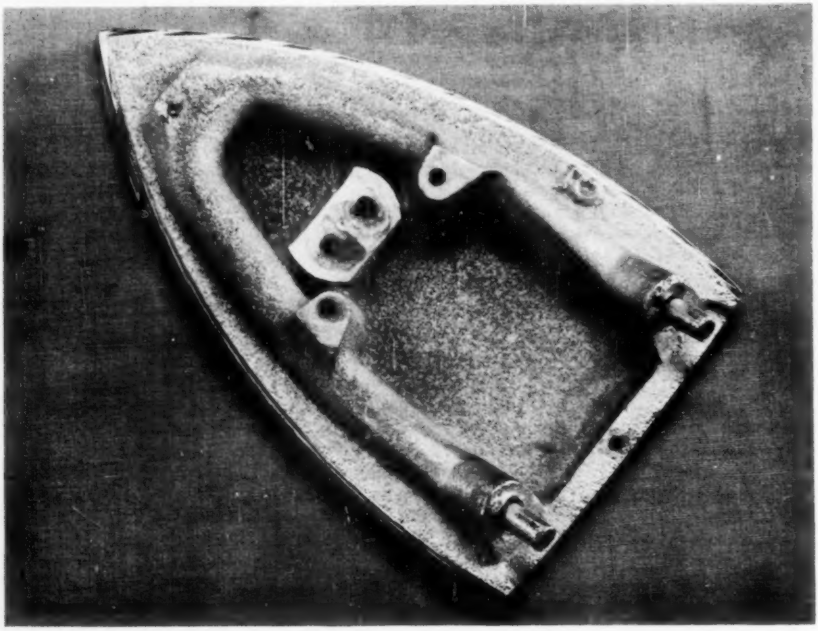
One of the most valuable routine applications has been on thermostat contact pressure and thermostat rocker arm pressure. Both of these quality characteristics are influenced by the form of the contact spring and adjusting spring. Due to changes in form for various lots upon heat treating a gaging and hand forming operation has been found necessary. The foreman of the thermostat section governs the setting of the gage for spring forming by the $\bar{X}$, R Charts on contact and rocker arm pressures.

It is interesting to note that we started this job with a regular Shewhart control chart several years ago. Perhaps we have had exceptional foremen in this position, but we have experienced very little difficulty in getting the idea of control limits established as compared to specification limits. Perhaps one device that has helped in this regard is the use of the out-of-bounds area (cross-hatched) that is figured in from the specification limits. (See Figure 1). This device and its calculation have been covered in the literature.[1][2] You will note that in addition to these so-called modified limits we have used conventional 3-sigma statistical limits to define the normal operation. This has the beneficial effect of keeping the process adjusted to the most desirable value. A point outside of statistical limits, but yet not out of bounds, would not be outside of specification. Product could be accepted for assembly into flatirons but action should be started toward readjusting spring form to bring pressures back to normal. The cross-hatched area, as appears in Figure 1, sets forth the concept that due to the variation of individual items the average must be carried at a safe distance inside

the specification to keep from getting individual items outside specification limits. We have found this concept readily accepted by shop personnel.

In many cases the quality control engineer is so imbued with a routine plan for controlling the over-all quality of a manufacturing operation that he is liable to make use of control charts only if they fit into this plan. If he does this he is not getting maximum use out of a very versatile tool. It is like using a hammer just for driving nails. A hammer can also be used for beating things back into shape.

Both the $\bar{\bar{X}}$, R Chart and the p Chart can be used for special, short term investigations. Special data may be collected for such a chart when the data is not available from routine inspection records.



An example of what I am talking about is best illustrated by the following. Figure 2 shows a castiron soleplate with the cast in calrod heating element. Since this is a sand casting it is necessary to thoroughly clean the sand off before the machining operations are performed in order to lengthen cutter life. To accomplish this the castings are tumbled in a special device filled with cascading shot. While the casting is being cleaned a small amount of the magnesium oxide insulating powder becomes loosened and falls out the ends of the calrod. This is an advantage since it leaves a slight recess to receive a sealing compound which seals the unit against penetration of oil and plating solutions. We started experiencing excessive losses of castiron castings at the head of our assembly line where the sheath is trimmed off at the ends to expose the calrod terminals. The reason for this was that excess insulating powder was being removed in a percentage of soleplates. When these were trimmed the

sheath would collapse and the casting was lost. Since we had no inspection point at the head of the conveyor, we would learn of extensive losses after several hundred soleplates had been accumulated over a period of a week or two.

It was decided this loss could be prevented by the operator filling the ends of the calrod with sealing compound. When he came to a casting that looked as though it had had excess powder knocked out of it, he would gage the surface of the powder with relation to the surface of the casting. This casting would then be set aside and filled with an electrical insulating cement which was allowed to set and dry out before sealing.

Although the weekly accumulations of scrapped soleplates at the sheath trimming operation dropped off somewhat, losses were still high. Preliminary investigation showed that the operator was not making full use of the gage on doubtful cases. After this was corrected, losses from accumulated scrap was still high. In order to tell what was going on we decided to get a daily count of castings lost at the sheath trimming operation. Since this was not a routine inspection point, an engineering assistant was asked to spend a few minutes at the end of the day to count the castings the operator has thrown out. The resulting data were kept on a p chart as shown in Figure 3. It was evident that for a few days losses would be low and then they would rise, then they would drop again. A cycle seemed to be apparent. This pattern seemed to be established by the fact that lots of "powder out" castings that needed filling with insulating cement were accumulated, filled and sent through subsequent processes in a lot. This immediately indicated that something had gone sour with the salvaging operation. Investigation showed the cement was not setting up properly. In fact it was nothing but powder. Further investigation showed that the operator was not properly mixing the binder in the cement. Another mystery solved by a relatively short range use of a p chart.

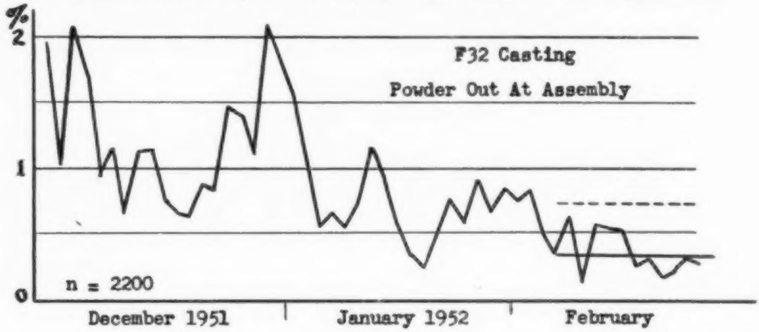


Figure 3

The $\bar{X}$, R Chart also lends itself to short range investigational work. Rather than use the somewhat involved mathematical process encountered in analysis of variance, an $\bar{X}$, R Chart will often do the job.

In making a certain temperature check, flatirons are tested on a device equipped with fourteen thermocouples. We were suspicious that one of the fourteen thermocouples might be giving us incorrect readings. One method would have been to run a test iron of known temperature over each of the thermocouples. This would have caused a shutdown of the device

for a considerable duration and given us results under highly artificial circumstances, i.e., with extended time to establish equilibrium and with only one given iron at one given temperature.

Rather we recorded a series of flatiron temperatures for each thermocouple as appears in Table I. The readings for each thermocouple number were treated as a subgroup and given the $\bar{X}$, R analysis to answer the question: "Is the variation from thermocouple to thermocouple greater than would be expected from the normal variation of flatiron temperatures presented at random to the thermocouples?" Thermocouple No. 9 which had more high readings than one might expect, was within three sigma control limits. (See Figure 4)

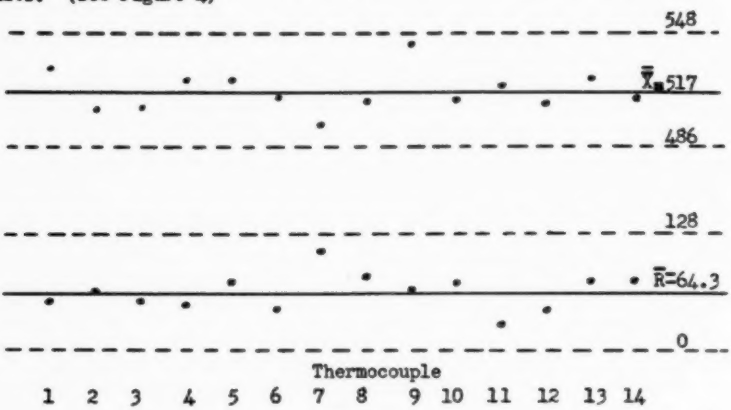


Figure 4

TABLE I

TEMPERATURE READING, °F.

Determination No.

Thermocouple Number	1	2	3	4	5	6	Total	Avg.	Range
1	525	530	530	550	550	495	3180	530	55
2	510	535	470	500	505	530	3050	508	65
3	530	540	500	500	495	485	3050	508	55
4	515	525	535	505	505	555	3140	523	50
5	520	560	515	510	550	485	3140	523	75
6	530	510	515	490	535	505	3085	514	45
7	440	550	[illegible]	520	495	500	2985	498	110
8	470	520	505	505	550	520	3070	512	80
9	530	550	580	555	515	530	3260	543	65
10	520	515	475	520	550	495	3075	513	75
11	510	505	515	535	530	525	3120	520	30
12	500	535	515	510	490	510	3060	510	45
13	530	525	495	565	490	540	3145	524	75
14	485	480	490	555	535	540	3085	514	75
							TOTAL	7240	900

Underlined values not within specification.

$\bar{R} = 64.3$ $\quad n = 6$ $\quad \bar{\bar{X}} = 517$

$UCL_R = (2.004)(64.3) = 128$ $\quad UCL_{\bar{X}} = 517 + (.483)(64.3) = 548$

$LCL_R = (0)(64.3) = 0$ $\quad LCL_{\bar{X}} = 517 - (.483)(64.3) = 486$

A second series of six readings for each thermocouple was taken (not shown). Again the average readings for thermocouple No. 9 was within three sigma limits, actually plus 1.4 sigma from the mean of all thermocouples. This indicated a possible chance variation, but singled out thermocouple No. 9 for further check. All thermocouples were found to be satisfactory and attention was then given to obtaining less variation in the setting of calibration of the flatiron thermostats.

Figure 5

Figure 5 shows the picture of a handle for one of our flatirons. The open gap beneath the handle is bridged by a decorative metal nameplate that covers the top of the iron. Although the plastic handle is placed on a cooling fixture, which spaces this gap, we have had trouble holding the dimension due to the varying degrees of warpage of "pulling in" after removal from the cooling fixture. The tendency to "pull in" is a function of the "cure" on a handle. "Cure time" or the time the handle remains in the mold after being formed, has to be established for plastic compound of given flow rate (rate of plastic flow under heat and pressure). The flow rate varies from blend to blend of molding compound. If it varies too widely, the "soft" blends of compound result in inadequate cure and warpage results. (Other important factors governing cure time are mold temperature and temperature of preforms coming from the preheaters.)

In an endeavor to gain better control of our incoming molding compound, a sample of each blend of compound will be taken. Ten handles will be molded from each sample under essentially the same conditions, i.e., same press, same preheater, same operator, same cooling fixtures, and steam pressure closely controlled. The handles will be measured for length of gap. The measurements from handles from a given blend number will be treated as a sub-group and given the $\bar{X}$, R test to see which blends depart from what we might normally expect. "Out of control" blends will either

have to be returned to the vendor or we will have to set up special conditions to insure proper cure. Since we receive ten to twenty blends in a shipment, it should not take long to obtain sufficient number of blends to permit calculation of control limits.

We have had statistical quality control for almost ten years and we have been molding plastic handles for more than ten years, yet you see we are just now making a special application of the control chart to a problem that has recently proven troublesome.

The control chart is a very useful tool and should be used not only for routine process control but for special applications such as those I have been discussing.

In conclusion we might review the questions raised at the beginning of this paper and form some opinions. I think that the Shewhart control chart by itself may be difficult for shop personnel due to confusion between limits for averages and specification limits for individual items; however, much of this confusion can be overcome by use of an "out of bounds" zone on the chart as shown in Figure 1.

The control chart is a very useful tool for the engineering laboratory and for relatively short range special investigational work. Its great value in this phase of quality control should not be overshadowed by its use in routine quality control plans.

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(1) Dimensional Quality Control Primer
Federal Products Corp. 1946

(2) Edward M. Schrock. Quality Control and Statistical Methods
Reinhold Publishing Co., New York, 1950 pp. 128 - 137

STATISTICAL COST CONTROL IN THE PAPER INDUSTRY

Carl E. Noble
Kimberly-Clark Corporation

Introduction The role played by statistical methods in the control and improvement of product quality during the past ten years has surpassed all expectations. However, industry has been slow to recognize that these methods can be applied profitably to the study and control of most processes yielding measurements which are subject to variation. One of the most lucrative fields of application outside of quality control is that of cost control. Similar statistical problems face the quality control engineer and the cost accountant. Both collect large masses of data which are subject to variation. They need the help of statistical methods in recognizing errors in the collection, tabulation, analysis, and interpretation of these data. The accountant is constantly being forced to answer the question, "How much deviation in standard cost should be tolerated before taking action upon the process?" Seldom does a daily or monthly cost equal its expected standard. Variation not only occurs, but is expected. Yet there generally exists no accepted allowable tolerance. Statistical methods can make a real contribution to cost accounting by providing a scientific procedure of establishing reasonable tolerance limits. The accountant may also find the quality control chart a useful aid in a cost control system. This chart offers one of the best techniques yet found for presenting quality and cost data.

Sampling and Measuring of Cost Data One of the important factors contributing to the failure of statistical methods to gain widespread acceptance in the Paper Industry has been the difficulty encountered in obtaining a random sample from the processes manufacturing rolls, skids, batch mixtures, etc. While this factor has been instrumental in discouraging the use of statistical methods, in reality it makes an understanding of these methods imperative if one is to control his quality and costs most efficiently. Many times it is impossible to secure an unbiased sample in a roll of paper. The precision of an estimate based upon a biased sample can hardly be determined by judgment alone. The literature is filled with examples in which erroneous conclusions have been drawn about a population from data based upon a sample taken from only a segment of this population (2). Even when both the sampling and measuring of an item are free of bias, the normal variation in the population (of say paper) and in the measuring techniques has to be understood in order to interpret measurements of the sample properly.

The discrepancies in quantities of raw materials consumed offer an example worthy of consideration. These quantities depend upon such items as pulp and paper moisture, proper proportioning of raw materials, consistency regulation, broke determinations, sewer losses, and estimates of in-process and other constantly changing inventories. The measurements of these items are not only subject to variation, but are quite prone to be biased at times. It is not uncommon for a raw materials discrepancy of \$3000 or \$4000 to appear at the end of a month in a certain operation. If a discrepancy of \$4000 is reasonable in view of the normal variation in the sampling and measuring of the above mentioned items, then one of two steps should be taken:

(a) This discrepancy should be tolerated as an expected event and without too much commotion. Too often another \$2000 is

spent in a fruitless effort to find the cause of the discrepancy, or
(b) More and better measurements should be obtained, usually at additional cost, to remove the possibility of such a large discrepancy occurring by chance causes alone.

When biases in the sampling and measuring systems are likely to introduce large discrepancies, it is generally wise to establish modest checks on these systems. For instance, the central laboratory might check daily one of the bales of pulp or rolls of paper tested for moisture by the regular testers. The control chart aids in interpretating the differences in results from the two independent tests. This procedure often proves easier and less expensive than searching for errors o only after bias is suspected at the end of a month. Such biases as those from operator carelessness disappear when the campaign is launched to find them. The real cause of the bias is never found. The installation of a modest check system upon a testing operation has not only supplied more accurate measurements, but has actually increased the tester's interest in his work. Too many testing jobs exist where there is no gauge for evaluating the accuracy of work and in turn no real recognition of good work.

Control Chart in Cost Accounting Much time has been spent in emphasizing the necessity of securing the most accurate and reliable quality and cost data because the best methods of analysis, presentation and interpretation go to no avail if these data are inaccurate. With accurate data available one is in the position to make predictions and decisions about his operations. The control chart has been found most useful as an aid to operators and others in making decisions about product quality. This chart can be equally valuable as an aid in making decisions about costs. The accountant needs the statistical approach for setting limits within which he can expect cost measurements to vary even though the basic cause system producing these measurements remains relatively constant. There can be gained an understanding among those concerned that variation within these limits should generally be tolerated, but that a measurement outside these limits dictates that some action must be taken on the process. The method of calculating these tolerance limits is described with an example.

An Example of Control of Paper Waste The cost accountant is asked to set up a system for controlling waste in a certain department converting rolls of paper into sheets. The pounds of waste are recorded by shifts for a period of ten days. Figure I shows the results. The data are restricted to ten days in this example for simplicity. Actually, the data should cover at least one month or even three to six months if there exists suitable back records.

Figure I. Pounds of Paper Waste By Shifts

		Days									
		1	2	3	4	5	6	7	8	9	10
Shifts	A	89	112	121	91	75	86	123	98	96	97
	B	99	108	106	117	79	105	106	100	83	114
	C	115	132	103	98	81	93	105	114	87	124
	$\bar{X}$	101	117.3	110	102	78.3	94.7	111.3	104	88.7	111.7
	R	26	24	18	26	6	19	18	16	13	27

The average and range of the three shifts measurements during a day are represented by $\bar{X}$ and R respectively in Figure I. The averages of the $\bar{X}$'s and R's are given by the formulas,

$$\bar{\bar{X}} = 1019/10 = 101.9 \text{ and } \bar{R} = 193/10 = 19.3$$

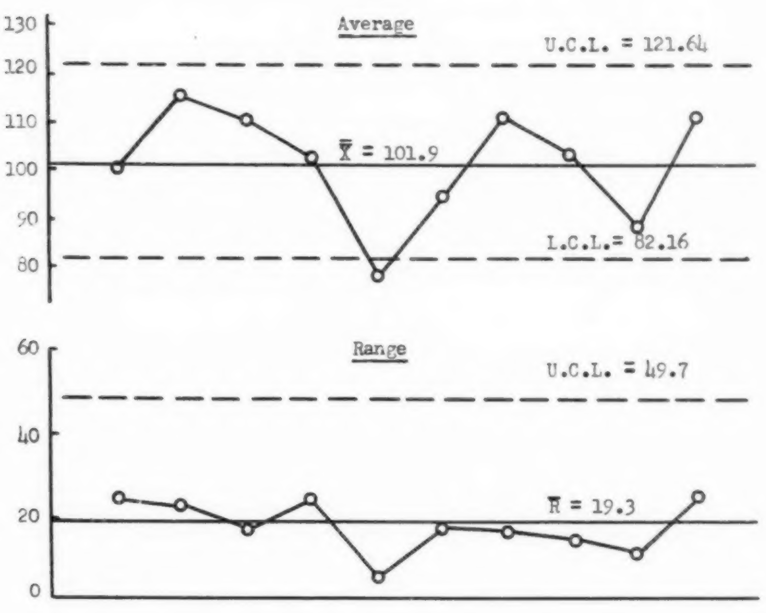
The central line on the control chart for $\bar{X}$ is $\bar{\bar{X}}$ and the 3σ control limits* for this chart are,

$$\text{U.C.L.} = \bar{\bar{X}} + A_2\bar{R} = 101.9 + (1.023)(19.3) = 121.64$$
$$\text{L.C.L.} = \bar{\bar{X}} - A_2\bar{R} = 101.9 - (1.023)(19.3) = 82.16,$$

where A_2, as well as D_3, D_4 and d_2 mentioned later, is defined in reference (1). The central line for the R control chart is $\bar{R}$ and the 3σ control limits are:

$$\text{U.C.L.} = D_4\bar{R} = (2.575)(19.3) = 49.70$$
$$\text{L.C.L.} = D_3\bar{R} = (0)(19.3) = 0$$

Figure II. Control Charts for Paper Waste (Pounds)



* Theoretically, the probability is approximately 0.003 that a value will fall outside its 3σ control limits by chance alone (1).

The $\bar{X}$ and R control charts are shown in Figure II. It may be seen that the R's lie well within the limits on the range chart, but one of the $\bar{X}$'s is below the L.C.L. on the $\bar{X}$ chart. Ten samples are an insufficient number on which to base a reliable decision that a process is in satisfactory control. Caution should be exercised in projecting the calculated control limits to serve as limits for future control of the process, particularly when one of the $\bar{X}$'s is outside the control limits. After twenty-five to fifty samples have been recorded, then the control limits should be recalculated. If not more than an average of one out of thirty-five of the $\bar{X}$'s or the R's fall outside their respective limits, then one can have considerable confidence that the process is in satisfactory control, and these limits can be projected and used as an index of control of future waste.

The process being in control means that the basic factors contributing to the waste (or any other cost figure) are relatively constant and that variation in the actual pounds of waste is due only to chance causes, causes that either cannot be removed or cannot be removed profitably. Since variation in the actual waste is going to take place within the control limits even though the basic cause system remains constant, it is assumed that no change takes place in the basic cause system as long as the actual waste falls within the control limits. If an $\bar{X}$ or R falls outside the control limits, then this assumption is rejected and action is taken on the process to investigate the reason the basic cause system has changed.

When a standard number of pounds of waste per shift has been calculated over a long period of time and found to be reliable, the standard rather than $\bar{X}$ is generally used as the center of the $\bar{X}$ control chart, and the control limits become <u>standard</u> $\pm A_2\bar{R}$. If one wishes to plot the total number of pounds of waste for the day instead of the average number per shift he multiplies the standard and the control limits calculated above by three to get the standard and control limits for the total waste during the three shifts. Finally, when the problem is that of setting control limits for the waste of the individual shifts, the standard deviation σ of the individual shift figures is calculated by dividing $\bar{R}$ by d_2. That is:

$$\sigma = \bar{R}/d_2 = 19.3/1.693 = 11.40$$

The control limits are <u>standard</u> $\pm$ 3(11.40) or <u>standard</u> $\pm$ 34.20. If $\bar{\bar{X}}$ is used as the central line on the $\bar{X}$ chart, the control limits are 101.9 $\pm$ 34.20.

<u>Establishment of Control Chart Limits on Basis of Variation From Day To Day</u> It is a good policy to secure a measure of variation, within the day, such as the range between the three shift figures, when the problem involves setting control limits for a daily cost. If the department or machine operates only one shift, then the production, waste, etc. may be recorded by hour or two hour periods with the range between these periods being a measure of within day variation. However, in a great many situations the accountant obtains only one cost measurement a day (or a month) for a machine or department and he wishes to establish control limits for this daily measurement. A method of calculating these control limits will be described with an example.

A particular department is expected to produce a standard number of container units per machine hour of operation. The deviations (called variances in cost literature) in the number produced from the standard are shown in Figure III for thirty consecutive days.

Figure III. Deviation in Number of Container Units Produced Daily

Day	Deviation (X)	Range $\lvert X_i - X_{i+1} \rvert$	Day	Deviation (X)	Range $\lvert X_i - X_{i+1} \rvert$
1	-12		16	7	25
2	26	38	17	24	17
3	-36	62	18	5	19
4	-30	6	19	- 3	8
5	34	64	20	-44	41
6	8	28	21	-45	4
7	34	28	22	1	46
8	-24	58	23	-12	13
9	40	64	24	18	30
10	-26	66	25	-27	45
11	69	95	26	-48	21
12	-38	107	27	-57	9
13	0	38	28	23	80
14	84	84	29	98	75
15	32	52	30	-32	130
				+69	1353

Average Deviation = 2.30   Average Range = 46.66

These thirty daily measurements could be divided into ten subgroups of three each. By finding the range of the three measurements within each of the subgroups, one could proceed in somewhat the same manner as described in the previous example. However, the most successful approach in handling these types of daily measurements has involved the calculation of the ranges R of the consecutive daily measurements as shown in Figure III. To check whether such R values could have come from a controlled process, the upper 3σ control limit for these R's is calculated. This upper limit is:

$$D_4\bar{R} = (3.268)(46.66) = 152.48$$

All of the R's in Figure III. are less than this limit. Furthermore, only one of the R's is above the upper 2σ control limit [= (2.512) (46.66) or 117.21] for R. Hence, it is reasonable to assume that the process is in good control. The standard deviation σ of the daily measurements is then estimated from the formula:

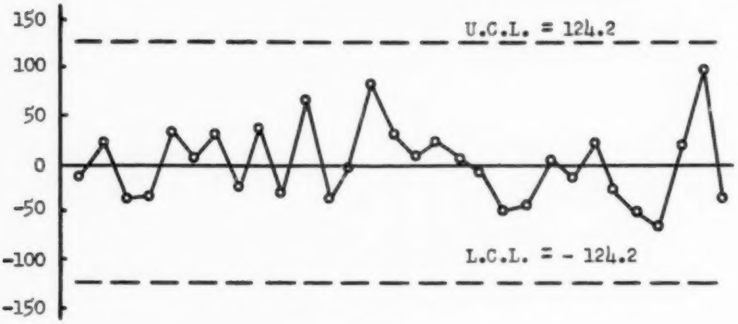
$$\sigma = \bar{R}/d_2 = 46.66/1.128 = 41.4,$$

where d_2 is based upon a sample of size two. Since the average 2.30 of the thirty measurements differ only slightly from the standard of 0, 0 is taken as the center of the control chart. The 3σ control limits for these daily measurements are:

$$\text{U.C.L.} = 0 + 3(41.4) = 124.2$$
$$\text{L.C.L.} = 0 - 3(41.4) = -124.2$$

The control chart in Figure IV. pictures these thirty measurements along with the 3σ control limits.

Figure IV. Control Chart of Deviations in Number of Container Units



The 2σ control limits have been found more acceptable in many of the cost control charts. This is particularly true where points outside the control limits may be investigated without too much effort. Furthermore, the method of using ranges of consecutive days often gives too wide control limits because these ranges are affected not only by chance variation, but also by real shifts in the level of the basic cause system from day to day. Thus, the probability of a measurement falling outside the 2σ control limits is usually less than 0.05, approximately the probability normally associated with 2σ limits (1). The fact that these ranges may include real shifts in level of the basic cause system necessitates that a careful job of rationalization be performed upon the data. That is, those data covering the period when an abnormal portion of the ranges fall outside their 2σ or 3σ limits should be removed and a new $\bar{R}$ calculated and used as the basis for the control chart limits. The rationalization is further complicated if the ranges are taken over three or four, rather than two, consecutive days since a shift in the level of the basic cause system is more likely to occur. When the ranges and in turn the process are hopelessly out of control, one should strive to get the process in a state of control before calculating the control limits. Little confidence can be placed in control chart limits based upon data collected from an out-of-control process.

General Applications of Cost Control Charts The measurements shown in Figure III are typical of such cost measurements as those for production, waste, labor, raw materials discrepancies, maintenance, research, and others too numerous to mention. The measurements may be on an hourly, shift, daily, or monthly basis. In any case the control chart approach provides a scientific manner of obtaining the limits in which a cost measurement can be expected to vary.

The establishment of limits for monthly cost can greatly aid in the interpretation of these costs. However, there are two serious weaknesses in too much dependence upon monthly cost analysis for control.

The first is the delay factor which might involve waiting until the middle of the following month to learn that an operation fell below standard the first part of a month. The second factor is that monthly costs often cover a heterogeneous set of operations over many days, machines, and crews and typify none of the actual operations. It is difficult both to find the cause of high costs and to place responsibility for them. For these and other reasons, (a) place control charts in the production departments where they can be observed by the operators, (b) let each point on the charts represent a particular operator or crews' efforts and represent as small a unit of production as practical, (c) place the points on the chart as soon as possible, and (d) let the charted points represent units, such as pounds of waste and rolls of paper, which are meaningful to the operators.

Experience in quality control has shown that there is no way yet found for bettering the control chart medium of presenting data. Yet, the cost accountant may find it an unsurmountable task to place on the control chart all the figures on his pages of cost sheets. In such a situation he should consider calculating the control limits for these figures and recording a figure on his cost sheet in (say) red, blue, or green according as it is above the upper control limit , within the limit , or below the lower control limit respectively.

Conclusion This paper encourages the cost accountant in the Paper Industry to use statistical methods to aid in the interpretation of cost data. These methods can give him much needed insight into the biases and normal variation in his sampling and measuring systems. The control chart is described as a powerful aid in controlling and minimizing costs.

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THE HAMILTON STANDARD CONTINUOUS LOT PLOT PLAN

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Hamilton Standard Division of United Aircraft Corporation

The Continuous Lot Plot is an acceptance sampling plan by variables designed primarily for use in process inspection. It provides rapid economical inspection of repetitive small quantities when the producing process is operating well within specification limits.

As in Mr. Dodge's continuous sampling plan by attributes, from which it has been adapted, a required number of successive items must meet stipulated limits for the characteristic being checked. Sampling inspection then begins and continues until a failure occurs. Following a failure, the same number of successive items must again meet stipulated limits before sampling is renewed.

The average and spread of the process universe are established and a plan is selected which, to a known risk, guarantees detection of a process change before beyond specification items are accepted during sampling inspection.

Figure I illustrates how a process might change due to average shifting, spread increasing, average shifting and spread increasing simultaneously, average shifting and spread decreasing simultaneously and skewing of the distribution. When the original distribution so changes that a portion of the distribution exceeds the original process limits, it is desirable for acceptance control to detect this change, doing so before any appreciable portion exceeds specification limits. The smaller the relative area that exists between the process limit and the specification limit, the more difficult the detection of the process change. Solid black sections of the curve areas in Figure I show proportional areas for the different types of changes. The skewed curve has the smallest black area, but occurs so seldom in practice that it has been eliminated from consideration. A spread increase has the next smallest black area and is used as the basis for plan risks.

This basic risk area is set equal to the AOQL risks of Mr. Dodge's continuous sampling curves, and plans are selected accordingly, so that very few items can ever exceed specifications before the process change is discovered. Naturally, the greater the proportional area for any one set of conditions, the greater the AOQL, and the fewer the items requiring inspection.

Attribute sampling curves in Mr. Dodge's plan cover a multitude of possible plans. For simplification in practical use six plans have been selected. They are defined in Figure II by "i" and "f" where "i" is the number of successive items (10,20,30,40 or 50) and "f" is the sampling frequency (1/2,1/3,1/5,1/15,1/30 or 1/50). Sum-of-ranges curves are representative of process spreads while horizontal chart lines are indicative of the portion of the changed process curve lying between the original process limit and the specification limit.

The "i" and "f" combinations for any one vertical band on the chart are picked to cover the smallest process curve portion within that band, thus maintaining the overall plan risk for the most detrimental set of conditions.

A standard Hamilton Standard Lot Plot of fifty readings or a special one of thirty-three readings can be used to estimate the process universe average and spread. An example of the special type is illustrated in Figure III.

The Continuous Lot Plot form of Figure IV has been designed to conveniently record the results of inspection and serve as a permanent inspection record.

Sometimes a characteristic is so critical that it becomes necessary to check uninspected items which have been accepted during sampling inspection just prior to detecting a detrimental process change. A sampled item falling beyond stipulated process limits indicates such a change. The Screening Quantity Chart shown in Figure V has been prepared for finding the number of items which must be "backscreened" from the point of failure to include items manufactured since the process changed.

Plan operating mechanics are best illustrated by an example. Readings of a one-half inch length dimension are plotted on the Lot Plot form (Figure III). Process average and spread limits are calculated and plotted using Lot Plot methods. Specifications are also plotted. The sum (23) of six ranges of subgroups of five each and the distance in cells (2.44) from the process limit to the nearest specification are used in the Plan Selection Sheet (Figure II). A point determined by these two values falls in the vertical band of the chart designating use of the "i" = 30, "f" = 1/3 sampling plan.

Thirty successive readings have already been found within process limits and recorded on the Lot Plot (Figure III), so sampling of every third item can be immediately started.

Sampling inspection readings are recorded on the Continuous Lot Plot form (Figure IV) by lot number. Note that process average, process limits and specifications have been transcribed from the Lot Plot. Entries of readings following a failure are recorded with an added letter to facilitate counting the "i" successive number before renewing sampling.

*When a beyond specification reading occurs during inspection of a critical type characteristic, check all available items to eliminate those beyond specification. Less critical characteristics can be "backscreened". The changed process percent defective is estimated from dividing the number of items beyond specification by the total number inspected after the first defective was discovered. If seven defectives were found in one hundred inspected items, the top half of Figure V can be used to perform this division and shows the estimated process percent defective to be seven percent. The bottom half of the same chart shows that thirty-seven successive items accepted just prior to the discovery of the first defective should be inspected.

The Lot Plot uses Mr. Shewhart's average and range chart theory, formulae and principles for establishing process universe average and spread.

Curves in the Plan Selection Sheet are developed from the formulae employed by Mr. Dodge in computing his continuous attribute sampling curves. AOQL percentages were set equal to percentages of normal process curves existing between estimated process limits and specifications.

The lower curve in the Backscreening Chart is calculated from the Binomial formula : $P_o = (1-p)^n$, where $P_o = 0.1$, p = the fraction defective and n = the "backscreening" quantity. P_o being set equal to 0.1 gives a 90% assurance level to the curve.

The greatest gain from Continuous Lot Plot inspection comes from inspection savings when processes are operating well within specification. Lot Plots and Continuous Lot Plots can be referred to production personnel for interpretation and where indicated for correction of the production operation.

References :

" A Sampling Inspection Plan for Continuous Production " - H. F. Dodge
The Annals of Mathematical Statistics, Vol. 14, Sept. 1943

" Economic Control of Quality of Manufactured Product " - W. Shewhart
D. Van Nostrand Co., Inc., N. Y., 1931

* Critical characteristics are non-mating structural type requirements such as hardness and wall thickness. Less critical characteristics are mating types such as bolt holes, screw threads and location dimensions. The chart does not read below 4%, since less than 4% defective is considered acceptable without screening. This decision is based upon the low probability of resultant defective assemblies, the probability of defective assemblies being the product of the fraction defectives of the mating parts. For two parts the probability is .04 x .04 = .0016 or .16%.

FIGURE I

PROCESS CHANGES

CODE:

SP.L= SPECIFICATION LIMIT
OPL = ORIGINAL PROCESS LIMIT
OA = ORIGINAL PROCESS AVERAGE

NA = NEW PROCESS AVERAGE
NPL = NEW PROCESS LIMIT
NM = NEW PROCESS MODE

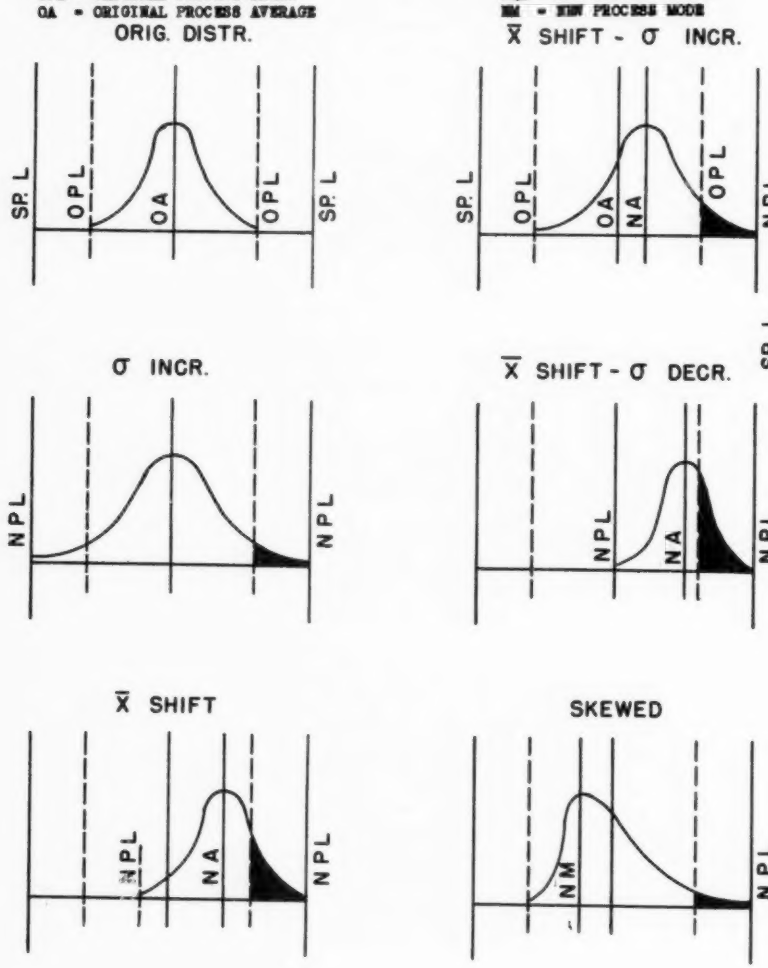


FIGURE II

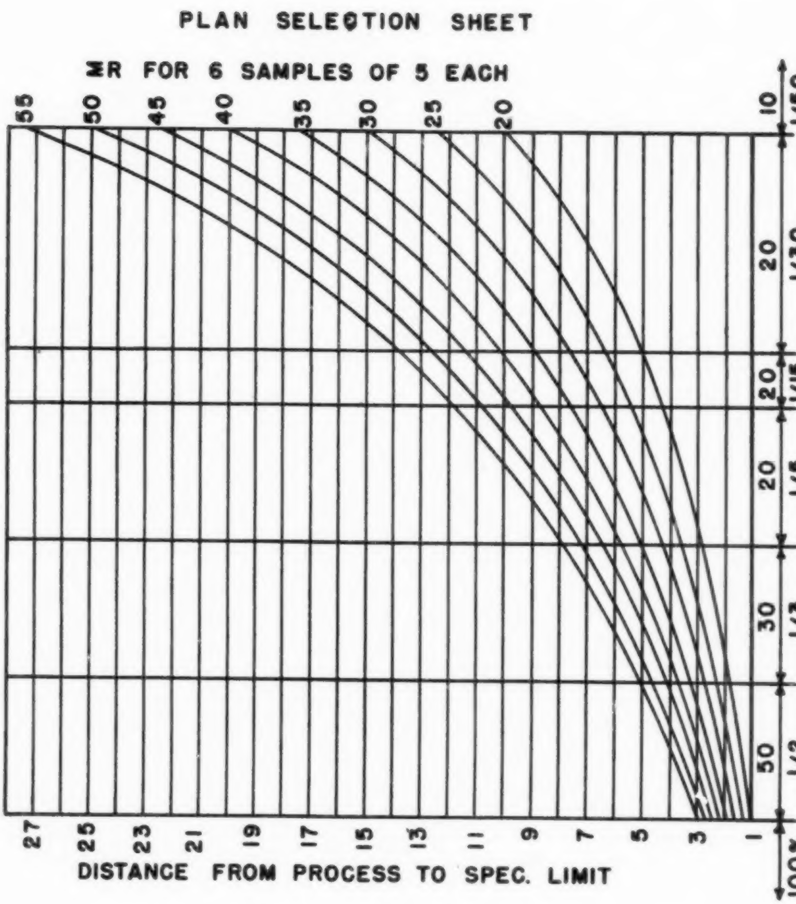

PLAN SELECTION SHEET
ΣR FOR 6 SAMPLES OF 5 EACH
55
50
45
40
35
30
25
20
10 1/50
20 1/30
20 1/15
20 1/5
30 1/3
50 1/2
100%
27
25
23
21
19
17
15
13
11
9
7
5
3
1
DISTANCE FROM PROCESS TO SPEC. LIMIT

FIGURE III

HSP F-5580

DATE REC'D. ______

HAMILTON STANDARD DIVISION
LOT PLOT AND SALVAGE ORDER

VENDOR – – – – – – PART NAME DOWEL PIN PART NO. 37298

P.O. NO. – – – – R.S. NO. – – – – QUANTITY 62 DATE INSP. 2/6/49

SPEC. .500 ± .010 LENGTH INSPECTOR #71 SAMPLE SIZE 33

VALUE	IND.	LINE NO.	5 · 10 · 15 · 20		
		+10			
		+9			
		+8			
.510	10	+7		UPPER SPEC.	
9	9	+6		2.44 CELLS	
8	8	+5			
7	7	+4		UPPER	
6	6	+3	4	PROCESS	0
5	5	+2	1 4	LIMIT	+3
4	4	+1	1 3 5		0
3	3	0	2 2 4 5 6 7		+1
2	2	-1	1 1 3 4 5 5 6 6 7	$\bar{X}$	0
1	1	-2	1 2 3 4 7		0
.500	0	-3	2 2 6 6		-2
.499	24	-4	3		0
8	23	-5	3		0
7	22	-6		LOWER	+2
6	21	-7		PROCESS	x 3
5	20	-8		LIMIT	+6 ÷ 100
4	19	-9			= +.06
.493	18	-10		LOWER SPEC.	

.490

PLEASE!

ASK YOUR OPERATOR TO STUDY THIS DIAGRAM AND—

	RANGE
1	4
2	3
3	6
4	5
5	2
6	3
7	
8	
9	
10	
11	
12	
13	
14	
15	
ΣR = 23	
3σ = 5.0	
ΣX = +2	
$\bar{X}$ = +.06	

☐ MOVE BASIC PRODUCTION SIZE (TOOL SETTING, DIE SIZE, MOLD CAVITY, ETC.) ______ IN ______ DIRECTION

☐ REDUCE PROCESS SPREAD AT LEAST ______

☐ MAKE THE TWO BASIC PRODUCTION SIZES CENTER AT ______

☐ EXPLAIN WHY RED CIRCLED PIECES WERE LEFT IN THE LOT

IF SOME OF THE ABOVE ARE CHECKED, LOOK FOR NEXT LOT PLOT TO SEE IF YOUR ADJUSTMENTS WERE SUCCESSFUL

☒ ACCEPT OUR CONGRATULATIONS FOR A GOOD JOB! THE OTHER SIDE OF THIS SHEET TELLS YOU HOW TO GET A CHECK MARK IN THIS LAST BOX ALL THE TIME

DISPOSITION	
ACCEPT (CO. INSP.)	[signature]
SALV. ACCEPT (HSP SALV.)	
GOV'T. INSPECTOR	

BEYOND	%	EXTENT
HIGH SPEC.		
LOW SPEC.		

ATTRIBUTE SAMPLE DATA

SAMPLE OF ____ SHOWS ____ PIECES ____

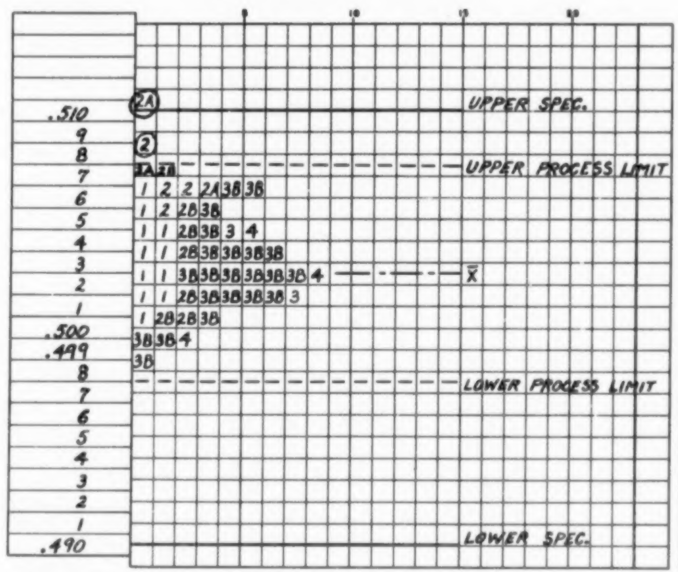
REMARKS— FROM PLAN SELECTION SHEET USING (23) + (2.44); i = 30, f = 1/3

FIGURE IV

HAMILTON STANDARD
CONTINUOUS LOT PLOT

VENDOR - - - - - PART NAME *DOWEL PIN* PART NO. *37298*

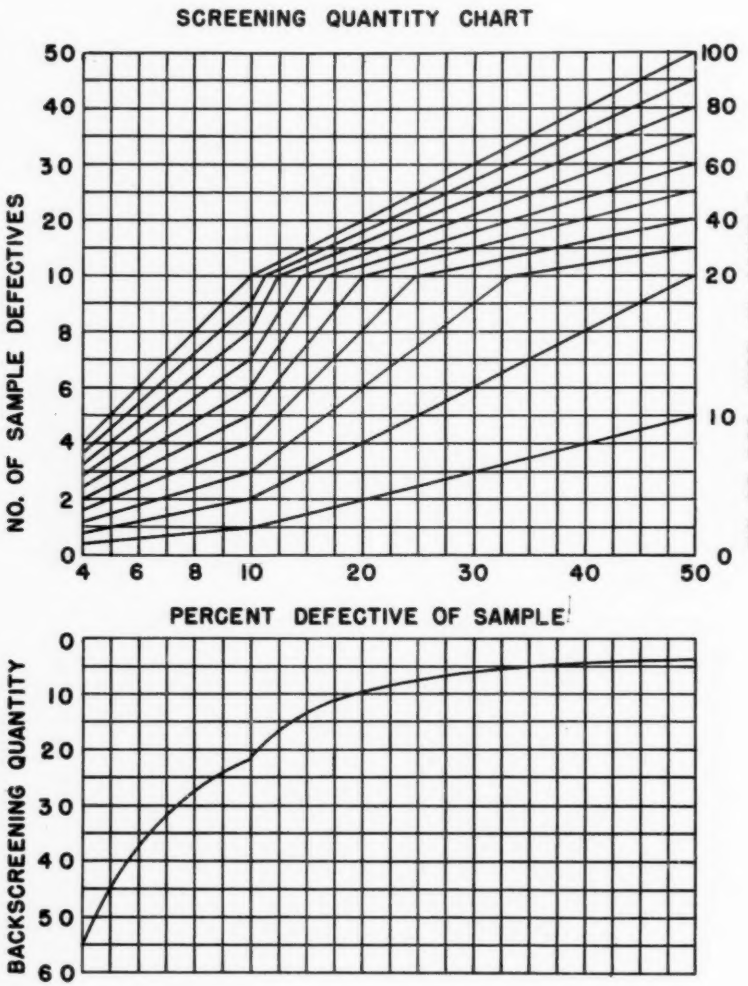
SPECIFICATION *.500 ± .010 LENGTH* SAMPLE SIZE *30-1/3*



LOT NO.	R.S. NO.	QUANTITIES	A	B	DATE	INSP.
1	–	65			–	–
2	–	20	3	7	–	–
3	–	29		23	–	–
4	–	7			–	–
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						

REMARKS: *SEE LOT PLOT FOR FIRST 39 PCS.*

FIGURE V


SCREENING QUANTITY CHART
NO. OF SAMPLE DEFECTIVES
NO. OF PCS. INSP. IN SAMPLE
PERCENT DEFECTIVE OF SAMPLE
BACKSCREENING QUANTITY
50
40
30
20
10
8
6
4
2
0
100
80
60
40
20
10
0
4
6
8
10
20
30
40
50
0
10
20
30
40
50
60

VOSP - A New Invention for Averaging Out Human Opinion in Visual Inspection

by Dorian Shainin, Chief Inspector
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East Hartford, Conn.

This paper summarizes some of the published work from around this country on the subject of visual inspection, and proposes a new plan for further study.

The Perfect Circle Corporation reported rather completely on the problem. (1). I have drawn upon other references to fill out the picture. Three main steps define one complete approach to the problem.

First specify the undesirable characteristics - blemish on a working surface, sand hole in casting, tool mark, etc. Establish a tolerance next based on your customer's reaction to the appearance as well as on the effect on suitability (performance, strength, or interchangeability). Dr. J. M. Juran has a proposal that fits here.(2) It is designed primarily to give data on the cost of quality as a factor in deciding what shall be the maximum acceptable level of the undesirable characteristic. His plan involves a range of samples classified by interested company departments. An estimate of the relative amount of current production falling into each class comes from sampling. The cost to the company of drawing the line at each class is then presented to top management for a decision.

Finally record the decision on the drawing - almost an impossibility and only partially aided by sample pieces or photographs that help the inspector's judgement. Just consider one example. Almost an infinite number of samples would be needed to cover all the borderline acceptable cases for sand holes in a casting.

Some test results sober us further. Inspectors without physical standards very seldom gave decisions that represented unanimous agreement. And when the same parts were presented at a later time, about one decision in every four was reversed. Oversights revealed in some later tests were mentioned in that report, but not prominently.

Tests at Hamilton Standard confirm the variability of opinion found at Perfect Circle. The oversight situation also is characteristic of all humans and must be recognized in a formal procedure set up to minimize poor visual inspection results.

Some schemes have been tried for controlling visual inspection. A piston ring problem of inspection for sand and gas holes benefitted from the adoption of sample rings. They had holes drilled to represent maximum acceptable sizes of defective areas. This worked even though the sand and gas holes were unevenly distributed and had irregular shapes. In addition to using this "standard", a check inspection had to be made. The results against each original inspector were charted; not only the number of defective rings found in accepted material, but also acceptable rings in rejected material.

David H. Schwartz of the United States Quartermaster Corps broke the error of inspector judgement into two types; consistent and inconsistent bias.(3) To detect the first, it being a too exacting or too liberal opinion, an independent check by another inspector is needed. Inconsistent bias can be found by one or more of three methods at a given probability level, presupposing a reasonably constant process average:

(i) A comparison of actual with expected frequency of rejection.
(ii) A check of the consecutive number of acceptances.
(iii) The extent of agreement between the actual and expected sample size (for multiple sampling plans).

The Calvert Distilling Company made check inspection itself fit a statistical plan.(4) For taste testing, ten inspectors were selected on their statistically significant ability to detect differences among whiskeys. They each stated from two pairs of trials which of the unknown samples was from a new batch. One involved a standard and the other trial from an eight to ten thousand gallon blend.

If their accumulated votes were correct within plus or minus 2.2 standard deviations of a p' of .50, the lot was acceptable. They were probably being forced to guess, because the new batch tasted like the standard. Taster's statements equal to or more than 75% correct (+2.2 $_p$) called for rejection. The difference was judged significantly enough to be beyond the range of guessing. But fewer correct than minus 2.2 $_p$ from p' of .50 meant the test was faulty. The procedure might have to be rerun more carefully since quite likely a bias crept in.

The above work has generally been aimed at bringing in top management to minimize inspector judgement by deciding on the acceptance level. The inspector then gets a standard for comparisons to make decisions. Hayes described this situation as one that needs correction. "Thus, the final decision is left up to a 'dollar an hour' inspector because a two or three dollar an hour engineer cannot describe what he wants."(1)

Juran, on activities where the appearance of the product is the most important quality characteristic, said, "In such industries it is quite common to find that inspectors at the 'bottom' of the organization are making decisions of the utmost importance to the life of the company. The inspectors have no choice, since the 'top' has failed to provide standards. In effect, the individual inspectors are setting tolerances."(2)

While they are less conspicuous, other elements have been touched upon. It is a plan that extends Peryam's work that is needed for the visual inspection problems of those industries where:

1. Standards are impractical to establish because they would have to be virtually infinite in number.
2. For the same reason, top management cannot draw the maximum acceptable line for the selection of each standard.
3. Oversights cannot be assumed to be few enough to neglect.
4. Without standards, the judgement of individual inspectors must still be kept measurably consistent, and with an acceptably small enough bias.
5. And yet the plan must be feasible, economically and otherwise.

The Hamilton Standard Visualing-Out Sampling Plan (VOSP) has these general characteristics. It is economical for obviously good or bad material as compared with 100% inspection, yet it operates at tighter risk levels. It classifies visual defects for two risk levels as those of appearance and those of omission of operations that are functionally needed. It narrows the risk of poor decisions when the disposition of the material becomes a matter of close opinions. And it recognizes that the basic role of inspectors is to report findings factually, accepting the material or diverting it for special review action and the role of foremen and the Material Review Board is to give opinions and to take the responsibility for them.

The plan follows this reasoning. Several inspectors will each check the same attribute sample from the lot. Obviously good or bad material should generally result in agreement among them (incidence of oversights can be found by cross checking their independently determined results). As visual defects approach the region of borderline decisions, the inspectors will be expected to differ more often.

A 50-50 split among inspectors means the borderline nature of the material forces them to guess. Upper and lower limits can be set to this p' of .50 where here fraction defective refers to the number of inspectors giving "incorrect" decisions. The region below the lower limit stands for results that should be acceptable. The region between limits represents borderline material. It should also be generally considered acceptable. The region beyond the upper limit is an area of sufficient agreement among inspectors that the lot should be rejected.

The number of inspectors needed for each lot will be determined by the sequential results of their findings. It will narrow the risk of poor decisions when close opinions are involved. This thinking fixed the sequential plan.

A conventional operating characteristic curve for the sequential plan should pass through the producer's risk probability of acceptance at an AQL of .50. We want borderline material accepted most of the time. The consumer's risk should be at a lot tolerance value equal to the upper limit of the fraction defective of inspectors rejecting the sample. Such material should be rejected most of the time. Trial and error computations showed a practical solution was to use a producer's risk of .20 and a consumer's risk of .05, with an AQL of .50 and a lot tolerance of .76. It kept the number of inspectors reasonable.

The points on the OC curve are reported this way purely for convenience in describing the position of the curve. The sequential plan results in a rejection from four consecutive decisions, while five acceptances take the lot. To avoid using an infinite number of inspectors, as inconsistent decisions are encountered for borderline material, the sequential plan was truncated. It was arbitrarily decided that for obviously good or bad material a maximum of three inspectors could give completely incorrect decisions on the same sample. Visual inspectors must of course be qualified as will be described shortly. With this restriction the maximum possible number of inspectors that could be involved because the material is quite borderline is eleven.

If no decision is reached by the time the eleventh inspector reports, the material will be considered acceptable. Form I is for the convenience of the supervisor who records the inspector's results. For a picture of the overall risk situation of this plan consider a three dimensional operating characteristic surface. First we have a plane containing the conventional OC curve of fraction defective of the incoming material plotted against the probability of its acceptance. Another OC curve is in a plane at right angles to this one. Its ordinate is probability of acceptance, in common with the first plane. The abscissa of this unconventional curve is the fraction of defective inspectors (inspectors giving wrong decisions). So the operating characteristic surface of the plan is made up of points that represent the resultant compound probability of the coordinates of the two separate operating characteristic conditions.

There are two ways in which material can be accepted, so the probability of each way has to be added. First we have the probability (if parts are

HAMILTON STANDARD SEQUENTIAL VOSP FORM #1
(P_1=.50; P_2=.76; α=.20; β=.05)

P.O. NO.____________________

R.S. NO.____________________

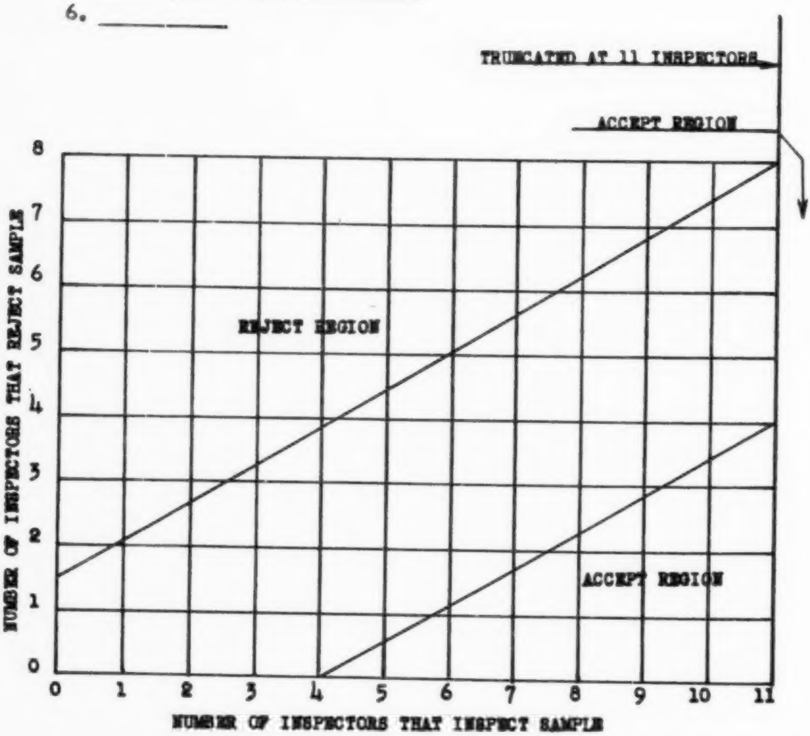
LOT QUANTITY ________________

DATE INSPECTED ______________

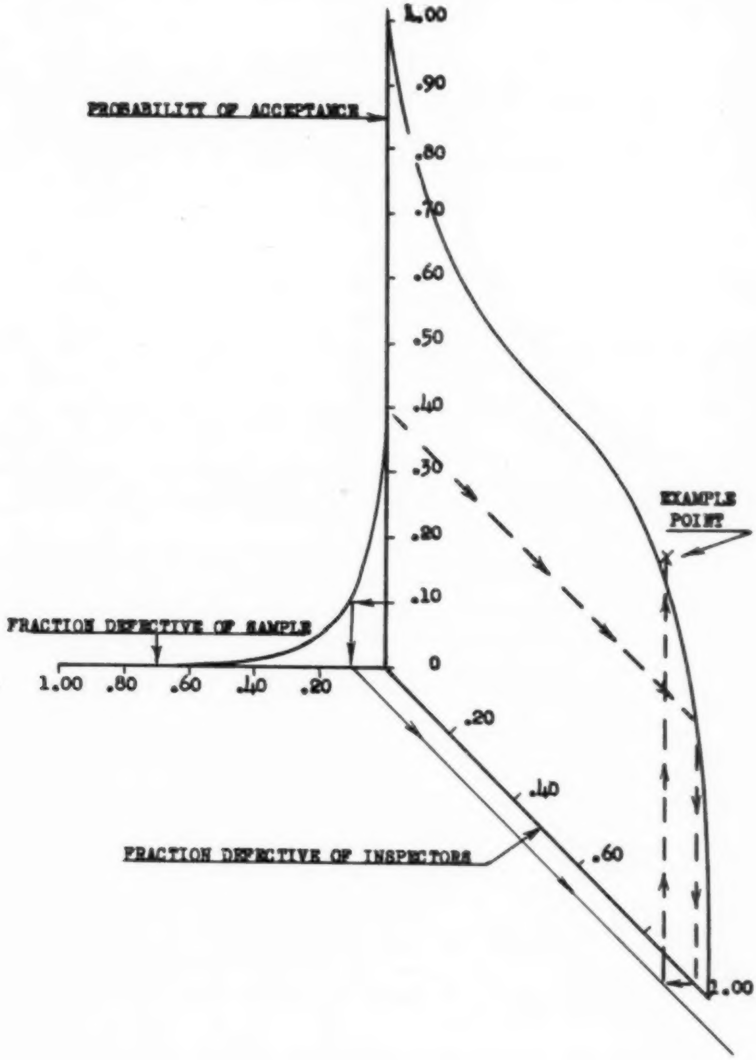
DATE RECEIVED ______________

INSPECTORS

1. __________	7. __________
2. __________	8. __________
3. __________	9. __________
4. __________	10. __________
5. __________	11. __________
6. __________	



OPERATING CHARACTERISTIC SURFACE FOR VOSP PLAN



good, inspectors will accept them) times the probability (the sampled parts are good). Next we have the probability (if parts are bad, inspectors will accept them) times the probability (one or more of the sampled parts is bad). Suppose the number of inspectors used and their fraction defective was such that the probability of inspectors giving sequentially correct decisions is .40. And suppose the probability of the sample being truly acceptable is .10. The combined probability of acceptance is then (.40 x .10) + (.60 x .90) = .58.

Much as in Peryam's situation visual inspectors can be selected by test of their ability to give "correct" decisions, applying their judgement to pre-selected sample pieces. The basic difference is that no standard other than a decision made by a hypothetically perfect Chief Inspector can be used. Accordingly, inspector candidates are checked against the prior decisions made by the current Chief Inspector on the samples. For their ability to avoid oversights, candidates are checked by standard psychological tests of the type available from The Psychological Corporation, 522 5th Avenue, N. Y. 18, N. Y.

Samples are selected strictly at random from the lot, employing a table of random numbers. Each piece in the lot is in effect assigned a number.

Two samples are employed. A sample of 75 pieces with no defects allowed serves to control appearance items. This plan has an AOQL of .4% to .5%. A sample of much larger size with no defects allowed will be tried for omission of operations and any functional visual requirements, although the illustrated form shows only 75 spots for noting errors of this type. A sample size of about 300 pieces is presently being considered. This will have an AOQL of 0.1%. Because of the high expected incidence of oversight with this size sample, this visual inspection has to be very carefully organized and must draw upon mechanical aids. For example a wire must be physically put through each oil hole to assure that it is there.

The sample pieces are placed in large box or series of boxes containing numbered compartments. Each compartment identifies the piece therein so that comparative results among inspectors on the same part can be checked.

The inspection procedure revolves around considering a part as a cube having six surfaces. Accordingly, as "standards", six additional parts from the lot are placed in front of the inspector with a different side or surface facing him. The inspector has a tally sheet with squares marked to correspond with the compartments of his sampling boxes. A coded notation enables him to describe quickly his findings as he compares each view of each part with the "standard". There is a likelihood of all parts being alike, but incorrectly so, such as having a missing oil hole. While the comparison checks would not catch the omission, the passing of this material is eliminated by the lot plots and/or attribute checks to blue print requirements made previous to applying VOSP.

The Operational Chart for the sequential plan schematically shows the suggested steps from three different starting conditions. If early in the inspection it becomes clear that each or nearly every item has the same error, the steps under "condition A" apply. By Material Review Board we mean the people responsible for making one of the three decisions shown for disposing of the material.

If the Board decides to have the lot screened for the particular error or errors found, a special graphical check should be made to see that the screening was at least reasonably effective. Binomial probability paper can readily give you the lower 90% confidence interval boundary (at minus

HAMILTON STANDARD VISUAL - SAMPLING PLAN VOSP FORM #2

P.O. NO. ____________________ INSPECTOR____________________
R.S. NO. ____________________ DATE REC'D.____________________
LOT QUANTITY ____________________ DATE INSPECTED ____________________
SAMPLE SIZE ____________________ PART NUMBER ____________________

VENDOR ____________________ PART NAME ____________________

1a 0	2a 0	3a 0	4a 0	5a 0	6a 0	7a 0	8a 0
9a 0	10a 0	11a 0	12a 0	13a 0	14a 0	15a 0	16a 0
17a 0	18a 0	19a 0	20a 0	21a 0	22a 0	23a 0	24a 0
25a 0	26a 0	27a 0	28a 0	29a 0	30a 0	31a 0	32a 0
33a 0	34a 0	35a 0	36a 0	37a 0	38a 0	39a 0	40a 0
41a 0	42a 0	43a 0	44a 0	45a 0	46a 0	47a 0	48a 0
49a 0	50a 0	51a 0	52a 0	53a 0	54a 0	55a 0	56a 0
57a 0	58a 0	59a 0	60a 0	61a 0	62a 0	63a 0	64a 0
65a 0	66a 0	67a 0	68a 0	69a 0	70a 0	71a 0	72a 0
73a 0	74a 0	75a 0					

APPEARANCE ERRORS (a)
1. POROSITY
2. TOOL MARKS
3. PITS
4.
5.
6.
7.

NUMBER OF APPEARANCE REJECTS ____________

NUMBER OF OMISSION REJECTS ____________

DISPOSITION OF LOT ____________
ACCEPT (CO. INSP.)____________
MR ACCEPT ____________
GOV'T ACCEPT____________

REMARKS ____________

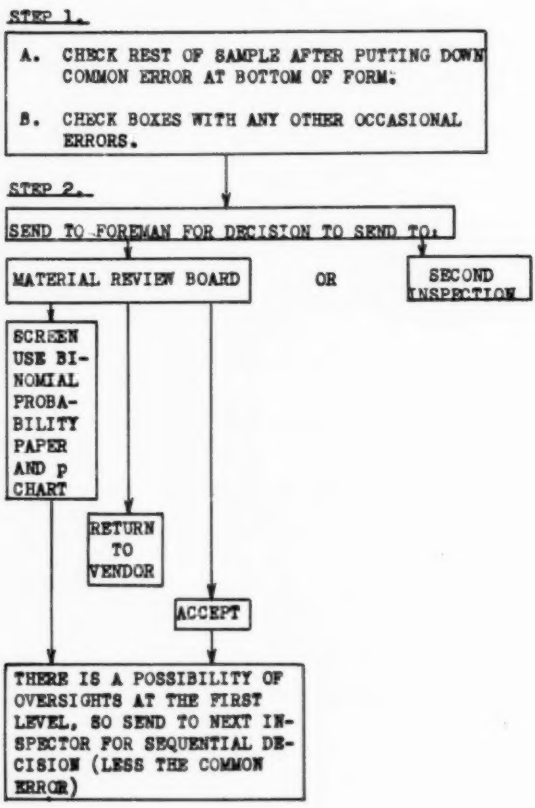
OMISSION ERRORS (O)
1.
2.
3.
4.
5.
6.
7.

OPERATIONAL CHART FOR SEQUENTIAL PLAN

(CONDITION A)

CONDITION A

IF FIRST MAN FINDS NEARLY EVERY PIECE HAS COMMON ERROR



OPERATIONAL CHART FOR SEQUENTIAL PLAN

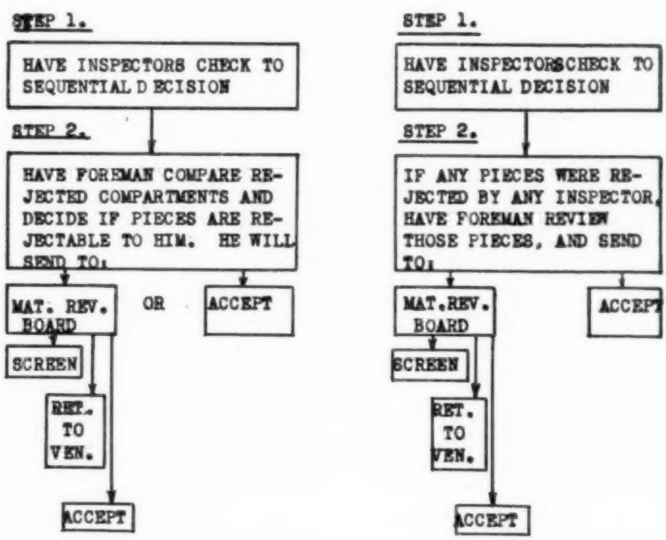
(CONDITIONS B & C)

CONDITION B

IF HE FINDS THE SAMPLE TO HAVE OCCASIONAL ERRORS

CONDITION C

IF HE FINDS THE SAMPLE ACCEPTABLE



1.65 standard errors) from the numbers of defective and good pieces found in the sample. An arc struck from the origin with a radius equal to the lot size will intersect this lower boundary radial line, also coming from the origin, at a certain ordinate. This reading is the "minimum" expected number of defective items for the lot. If your screening did not find this many rejectable pieces, screen again.

A p chart made from the results of the screenings describes well the efficiency of your multiple 100% checks. The results in the long run should be about equally distributed above and below $\overline{p}$, which in each case is the sample findings. Each point on the chart represents the fraction defective ratio of total items found in the single lot, which had to be screened, over the lot size.

Condition B refers to the cases where the first inspector finds only occasional errors within the sample. Here you see the foreman exercises his right to evaluate the "rejectable" items called to his attention by the inspectors' results. He must judge them when the inspectors do not agree on which pieces are rejectable. If the foreman sends the results to the Material Review Board for their more expert disposition, the result will be one of the same three we have for the other two Conditions - including a binomial probability paper check and p chart entry when screening is involved.

Condition C describes the first inspector as finding no defects. Under this or the previous condition, if an accept decision comes from the sequential results of the several inspectors, any pieces found rejectable by one or more inspectors will be looked at by the foreman.

Do you have any hesitation about whether VOSP is worthwhile? Here is a plan for trying it on a small scale that will answer your questions. Try it as described here for just a few part numbers with several of your inspectors. See if their independent decisions on the same samples agree. If they do, of course you will not need VOSP. What do you think will be the outcome of this test? Fortunately rhetorical questions do not require an answer.

(1) "Control of Visual Inspection", Aldis S. Hayes, Industrial Quality Control, May 1950, pgs. 73 - 76.

(2) "Establishing Standards for Nonnumerical Requirements", Quality-Control Handbook, McGraw-Hill Book Co. Inc., 1951, pgs. 63 - 65.

(3) "Statistical 'Sleuthing' to Detect Bias in Visual Inspection", Industrial Quality Control, May 1947, pgs. 14 - 17.

(4) "Quality Control in the Production of Blended Whiskey", David R. Peryam, Industrial Quality Control, November 1950, pgs. 17 - 21.

USING TRAINING CONFERENCES AS A QUALITY CONTROL CATALYST

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My talk today really had its inception in a couple of comments during the past year. One was at the last annual convention in Cleveland. A friend who was one of the real founders of the society commented on the really impressive group attending that convention: "Paul, I wonder if this thing isn't growing faster than we are." The second comment occurred at a luncheon at one of the General Electric Divisions where I was helping to conduct a conference. The general manager of the division asked me how industry was accepting quality control. I proceeded to repeat some of the "success stories" I knew. When I finished he asked quietly, "Now I'd like to hear your explanation of the failures."

These two remarks caused me to do a little re-examination of conscience. I sat down to study my own activities in the field of quality control, to see what answers I could find to the questions implied or asked.

Five years ago the function of statistical quality control seemed to be the use of control charts and acceptance sampling plans by the inspection department. The typical organization chart, if it showed such a function at all, showed it as a minor appendage of the inspection department, consisting of two or three people concerned with acceptance sampling plans and control charts on parts or products. The leaders in the field of quality control did not agree with this limited concept, but in general that was the status granted by industry. Indeed even this limited status has not as yet received acceptance by a large part of American industry.

When quality control was considered as the application of statistical methods to the inspection function, there was an obvious need for training in certain fundamentals of statistics. To a great extent the program sponsored by the Engineering, Science and Management Training Program of the War Production Board met this need. Some 2000 took the intensive course, and about 6000 more took part time courses. Since the end of the war many thousands more have taken similar training sponsored by colleges, industries, or sections of the American Society for Quality Control. The content of these courses is well known and does not need restatement here. It was and still is difficult to evaluate these training programs. I should like to give two quotations.

"These training programs have been the subject for high praise and biting criticism. They have been criticized because they emphasized the mathematics at the expense of explaining usefulness of the techniques. This was a valid criticism. Yet at the time there were available too few people who had a shop background and who at the same time were qualified as instructors. The best source of instructors was in men of mathematical background. Moreover the mathematicians themselves began to learn shop needs, and the courses began to be more practical.

Irrespective of these criticisms, these wartime training programs were the means for stimulating the imagination of thousand of men in many plants. The broadcasting of these seeds has grown, in record time, a crop of quality control enthusiasts. The influence of these men is beginning to make itself felt in industry." (1)

The second quotation gives another side of the story. "The usual experience in these intensive courses is to find that, initially, representatives from industry want and demand only so-called practical materials. After taking the course and making some use of their procedures, they learn the value of statistics and then decide that the difference between practice and theory is rather fuzzy, if a difference even exists. In fact, many take the view that what works in practice does so because it has a reason, and that the reason is the theory. It is these 'practical' people who ordinarily request additional 'theoretical' work. In fact, they often ask that what might be a semester's or a year's work, in mathematical statistics be presented during one forenoon, possibly in one hour; not only be presented but be set out in such a way that they can go back to their plant and use it in the particular problems at hand." (2)

As one of the "mathematicians who began to be practical" I know that there is essential truth in both of these quotations. There is no doubt that a large proportion of those who have had basic training in quality control have never used the training. There is also no doubt that many have found the theory of statistics fascinating and have pursued it on their own. Purely as a personal reaction I would suggest that it is interesting to note how practical some of the professors have become, and how theoretical the engineers can get.

It is just about ten years ago that I taught my first class in statistical quality control. At the time it seemed very practical to me. In the course of the next five years I taught a great many such courses. The course content was similar to that of the standard texts. The class discussions were practical in the sense that most of them were concerned with problems and case histories, rather than with statistical theory. The persons enrolled came from a variety of industries, generally at the lower level.

Several years ago I began to wonder whether this work had been of real value, other than that I was paid for it. I took the old class lists that I had and checked them over. I found that I could identify only a few who had continued any obvious connection with either statistics or quality control. I made an attempt to follow up on these ex-students of mine. I have by now checked up on a reasonable sample. Not counting the large group who were temporary war time employees, I find that they fall into three classifications.

The largest group by far are those who "found it interesting but we (the industry) never did anything with it and I've forgotten most of it." The second large group of lost sheep were those who "transferred to another department" or "went to a new industry." There was a small group who were still doing quality control work, irrespective of change of industry or job.

Now in many ways this record is nothing to be ashamed of. I think it will stand comparison with the imprint left on your minds by many college subjects. There is in this case a different basis for evaluation, however. In general these people came to learn how to control quality, incidentally, how to use statistics to control quality, and not to learn statistics as an intellectual discipline. If my objective had been to teach the elements of statistical method I may have been a success. If it had been to help control and improve the quality of manufactured product, this looked like five years of failure.

Why had these people made so little use of what they had learned? Again I can suggest a long list of answers. But in general they come down to

this: I had convinced them of the theory, and had given them some case histories. But I had not convinced their superiors, they had never gotten really started, and the shiny new tools had rusted away because they were never used.

I had done more harm than that. Many of the companies that sent young inspectors to such courses, had, mainly through lack of understanding of the aims and objectives of the program, severely handicapped them when they tried to apply these new and rather unfamiliar ideas. Many times the person achieved some success, such as getting a standard sampling plan initiated, after which progress stopped. Many people returned to their plants and reported: "It's a good theory but it would never work in this company." Now the over all evil results of much of my teaching is this: Many companies today say that they tried quality control and found it did not work, or had very limited applications, where they have really not given it a trial at all.

Moreover I am sure that this experience is not unique. Speaking at the convention last year in Cleveland Dr. J.M. Juran stated: "In a recent paper (3) I reported on the results of quality control programs started since World War II by 39 companies. The study disclosed a shocking mortality rate for these programs. The failures were due to failure to utilize the managerial tools for quality control while at the same time overemphasizing the statistical tools." Juran finds that elements common to a successful quality control program are:

1. A clear program, spelled out in advance
2. Concentration on this objective, rather than on any means to that end
3. A high degree of managerial competence in the quality department
4. A high level of shop participation and cooperation

The factors of adequate budget and technical competence of quality engineers were found to be of lesser importance.

This study by Juran is controversial. Quality Control is defined as defect prevention, and a successful quality program is one that cuts the cost of defects by 50%. The company names, naturally, are not given, so that one is not able to judge how representative the sample is. Many would not accept this definition of quality control. (4) However debateable some of the assumptions are I think that there may be general agreement with this conclusion: Too often our training efforts have concentrated on techniques, and neglected other elements necessary for success.

How can any training program attempt to meet these larger problems? I believe that the proper program can go a long way towards a solution, and that training conferences can really be a catalyst in getting a successful quality control program going. My remarks will, in general, concern plant or company training conferences. Many of the ideas have grown out of a close association with Ellis Ott, with whom I have worked in the Rutgers Conference Series on Quality Control, and in various company programs.

First I should define what I mean by Quality Control. I will use A.V. Fiegenbaum's definition: "Quality Control is an effective system for coordinating the quality maintenance and improvement efforts of all groups in the manufacturing process so as to enable production at the most economic levels consistent with full consumer satisfaction." (5)

Notice that quality control thus defined is not the function of any small group in the manufacturing organization. It is a function that involves many groups at different levels. Purchasing, Engineering, Research, Manufacturing, Sales - there is not a single division in the company that is not interested in quality control. The management, the different departments, and the key personnel must have a clear understanding of the functions of a quality program, and a good grasp of the basic concepts behind this program.

One method of insuring this understanding consists in setting up a special committee for the quality control program. At Continental Paper such a committee consisted of the executive vice president, and the managers of research, engineering, manufacturing, sales, industrial engineering, and personnel. The function of this committee is to define the program, and to review periodically the progress of the program. Only after this committee had a clear understanding of the objectives, functions and basic philosophy of the program did we move ahead. Let me assure you that the committee members have become vitally interested in the program, and that the question of top level management backing has never had to be raised.

Next comes the question of shop participation. If quality control is as important as we believe, the program should not be started with inspectors. The plant managers, superintendents, chief engineers, general foreman and foremen are the people who can make or break the quality program. If they are convinced that a quality control program is going to benefit them, the battle is won.

How much time is needed in conferences for this level of supervision? Their time is valuable, they will resent its being wasted. I suggest that six to eight meetings of approximately 90 minutes each will do. If this seems shockingly little, remember the purpose is not teaching statistics but getting an understanding and appreciation of what quality control is about, and how it can benefit them. This can be achieved in a short time, but only if we stick to certain principles.

The first principle is: Keep it simple.

The fundamental concepts of quality control are very simple. It has been a common experience that getting these basic concepts understood has been a difficult job in many industries. It is not my function today to present these in detail. Let me give an outline of a previous presentation. (6) The basic concepts might be listed as:

1. Any and all manufacturing processes exhibit variability.
2. There are two types of variability, chance or inherent variability- any variability that is assignable to specific causes that are economically worth finding and eliminating.
3. Inspection of a batch of finished product will distinguish between these two types of variability very inadequately.
4. Elimination or control of the causes of poor quality is the most important function of a quality program.
5. To control quality it is all important to reduce time in the manufacture-test-adjust cycle. To cut down this time element we must base our decisions on samples.
6. In general it is not possible to control a process by inspecting one or two sample items, classifying these as acceptable or defective.
7. The average of a small sample is much more sensitive to change in a process than are the individual measurements.

8. The range in a small sample can give a good measure of the inherent variability of a process.
9. A series of small samples can give a good estimate of process capabilities, as well as a good estimate of what it actually produced.
10. If quality data is worth taking, chart it, and use the chart for corrective action. If the chart does not lead to action, question the need for taking the data.
11. Inspection efficiency in routine 100% inspection is poor. Acceptance sampling of parts in process, and of final product, frequently will result in better quality.
12. Statistical techniques are a sensible tool to use in analyzing production and quality problems; they are not a substitute for experience and common sense.

The second principle is: Keep it visual.

Gadgets and models will enable a person to grasp a concept that hours of explanation will only confuse. Variability, both chance and assignable, may be demonstrated by a quincunx. Honest and crooked dice are even better for demonstrating the difference between the two types. Distribution models, with superimposed distributions of averages help the novice understand the principles of the control chart, as well as the inefficiency of attribute sampling.

Properly designed boxes of beads will demonstrate control of attribute measurements, and show the risks involved in acceptance sampling. Distribution models and sets of colored blocks show the combination of tolerances. A box of chips with the data from an actual process on them will demonstrate the difference between chance and assignable variability. Even such difficult topics as correlation and analysis of variance can be illustrated easily with three dimensional models.

The third principle is: Avoid statistical terminology.

This should be such an obvious principle that it is merely question as to whether it can be achieved. I believe it can, and that no statistical terms except average, median, range, and frequency distribution need be introduced. I include the median because I find that a control chart for medians is much easier for the beginner to understand. For one thing, if all the points corresponding to individual measurements are plotted, and the median indicated by a different symbol, there is no confusion between control limits and specification limits.

The fourth principle is: Keep to actual plant problems.

It may be alright to tell about how quality control works in some other plant at the first meeting, although I would not. After the first meeting throw away the text book problems, and go get some data right off the production line. This must be planned for well ahead of time, in the sense of having the necessary personnel, equipment, etc. If possible get data that is fresh off the job right at the time of the meeting. This is the big advantage of an in plant conference program. There should be no question of, "It's alright, but it wouldn't work here." By the time the conference is over it either worked or it didn't, but at least there is no question about it. This is why I call these sessions training conferences, and why I want all interested groups represented. If a part can be controlled to ± .0003 and the specifications are ± .0005, we want the design engineer sitting in to try and tell us if it is economically worth produ-

cing to these tighter specifications, or should we use modified limits to try and get increased production? If it is impossible to control the minor diameter of a cathode to the desired specification because of excessive variation in raw material, we want purchasing engineering and manufacturing to take on the job of doing something about it. Let me assure you that all the various elements of a quality control program will come into the picture. Questions of inspection procedure, tolerance design, gage control, etc., cannot be avoided. In the last such conference I conducted, I requested the management to make just one requirement. Each person had to bring in objective data, with an analysis, on one quality problem in his division. By the end of eight meetings we were not discussing quality control - we were doing quality control.

The fifth principle is: Keep it rolling.

The plant personnel that attend such a conference have a host of other problems demanding their attention. Unless there is a planned follow up, the effect of such a conference will die down. Quality control is dynamic and the problems of quality are constantly changing. The existence of the quality control committee gives an avenue for periodic review of the over all program. Care must be exercised by the quality control manager on follow up, lest it be considered criticism by production and engineering departments. It is here that the managerial competence of the quality control department head is most important. Avenues of communication on quality, must be kept open, not only from the top down, but also from the bottom up. The interest that has been aroused in the different departments must be nourished. But by now the quality control program should be well defined, have the support of management, the understanding of objectives and procedures by other departments, a high level of factory participation and cooperation and be on its way. Training conferences can really be a catalyst for quality control.

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MILITARY INSPECTION IN THE AERONAUTICAL FIELD

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Gentlemen, it is a pleasure to be with you today and to participate in this program discussing various aspects of military inspection in the field of aircraft and aircraft component equipment. General Bain has outlined to you, the purposes and objectives behind the establishment of the Air Force Quality Control Policy and their Specification MIL-Q-5923. It is my purpose to give you some reactions and opinions of the industry which is operating under this Air Force specification, particularly with respect to the effects of such regulations in our relations with subcontractors.

The Government-Industry Relationship

As you well know the health of the aeronautical industry is, to a very large degree, regulated by the procurement policies of the military services and funds made available by the Congress for the development and procurement of military equipment. Subject as we are to the vicissitudes of peace and war, it is only natural that we must become a large subcontracting industry. This situation necessitates very close and intimate relations between the prime contractor and his subcontractors, as well as good relations between the government and the industry as a whole. The problem of relations between the government and industry in the development of military aircraft and associated equipment has been a source of considerable study and varying opinions since the earliest days of aviation. Our relationship is somewhat unusual in this field since we must deal with the government as a buyer, as a renegotiator of our prices and our profits, as a collector of our taxes, and as an administrator of laws and regulations under which we operate. It is to the credit of both government and industry that the growth of United States air power has been accomplished without serious conflict in this unusual buyer and seller relationship.

Perhaps the greatest threat to the continuance of satisfactory relations between the aircraft industry and the government is that of over-regulation and over-control which can be carried to a point where traditional American incentives are lost in the tremendous welter of red tape. History reveals that although the government has been instrumental in some cases in accelerating development and production of aeronautical equipment through close control of the manufacturer, the most successful developments have been those in which the military services have allowed the company freedom in design and details of manufacturing operations. Unlike the British system where the government has assumed the major risks, both financial and technical, our fundamental United States concept particularly for production articles has been one in which the manufacturer assumed those risks based on rigid performance specifications and contractual guarantees. Our idea of the most productive arrangement between the government and aircraft industry is one in which we should operate as closely as possible to the strict buyer-seller relationship. This implies that emphasis be placed on the end results rather than on the method or procedure. The goal of policies and regulations should be to establish broad objectives, leaving the procurement agencies and the industry the freedom and flexibility they need to negotiate the technical terms and prices to do the job in the best way they know how.

Why Military Inspection

We are quite in agreement with the general purpose of military inspection of war production equipment and recognize that it serves two principal purposes, (1) it assures the taxpayer that its money is being spent to purchase equipment in accordance with government specifications and in the proper quantities, (2) it assures that military equipment is being produced true to specifications and of uniformly good quality.

The Air Force and the Navy Department Bureau of Aeronautics, have recognized the problem inherent to the government-industry relationship in the aeronautical field and have, in general, adopted policies governing inspection requirements which are basically sound. In carrying out their responsibilities, the Air Services have placed the primary emphasis on the responsibility of the industry for maintaining adequate quality control systems within their own facilities and throughout the facilities of subcontractors and vendors with whom they deal. The philosophy has been one of a surveillance type inspection as contrasted to complete detailed inspection, a task which is obviously beyond the financial and administrative capabilities of any single military or civil organization. Under such a philosophy, you may ask, what are the responsibilities of the industry and how does the military service define an adequate quality control system?

The Responsibilities of Government and Industry

It is a matter of actuality as well as official pronouncement that the responsibility to the nation for having available suitable aircraft and aeronautical equipment is held jointly by the military services and industry. The assignments, however, differ considerably. The services primary assignments are those of selection and operation. Industry's assignments are primarily those of development and manufacture. Inherent to its assignment, the military must establish and prescribe the performance and operational requirements for its equipment and must conduct the necessary inspection to determine that they are receiving equipment as ordered. Industry to the best of its ability, must meet these requirements, but in so doing it must of necessity have freedom of action. It must be guided by experienced people who know their business and it must use its own judgment in the design and fabrication of its products. The continued success of our national security program depends to a great extent on the effective recognition by both industry and the military services of these underlying principles.

In each prime contract for aircraft or aeronautical equipment, the manufacturer is required to maintain an "adequate quality control system" and before the product is acceptable to the services, the aircraft and its components must be designed and developed to pass rigid performance qualification and acceptance tests. In accepting these responsibilities, the prime contractors in industry must see that their own houses are in order as well as determining that their subcontractors and vendors are achieving proper quality levels for the articles they are producing. The aircraft industry is proud of its ability to expand rapidly and this expansion is only possible through the development of a satisfactory subcontracting base, and the adaptability of many suppliers to meet what are acknowledged to be highly complex and difficult standards. We find that new subcontractors, brought into this picture without prior experience with aeronautical government contracting, are pleased to find a fundamentally sound relationship

exists between prime contractors and subcontractors and between the Procuring Services and industry in general. It is safe to say that where difficulties arise in the subcontracting field, many can be traced to a misunderstanding or misinterpretation of some specific government requirement which is being imposed directly or indirectly upon the subcontractor.

Now how do the military services define an "adequate quality control system" in such a manner that the basic philosophy of surveillance type inspection will insure procurement of high quality articles? The Air Force has chosen to develop their requirements in the form of Specification MIL-Q-5923a. The Navy Bureau of Aeronautics has a similar but somewhat more general document known as Tl-48. There are some minor differences between the procedures employed, but in general they follow a similar philosophy very closely. The Navy document has been in effect since 1948 and has not undergone any change whereas the Air Force requirements have, in the interests of developing more specific definitions, been under more active revision since their original issue in 1950. For this reason I will confine my remarks to discussion of the Air Force specification, particularly with respect to what the industry expects in such a document, and whether this document actually meets the objectives of both industry and the Air Force.

There are four principles which industry feels essential to any government regulation which attempts to prescribe an adequate quality control system, (a) the standards should be well defined, (b) it should be based on practical product specifications, (c) it should eliminate duplication and red tape, (d) it should be written so as to provide for uniform administration in the field.

Does MIL-Q-5923 Provide Definite Standards?

Now let us examine MIL-Q-5923 to see if it meets the objectives as defined. First, are the standards well defined? The specification requires as a basic precept "verifiable evidence of quality". The Air Force has emphasized this in stating that Quality Control Policy which indicates conformance to contractual requirements is determined on the basis of objective quality evidence which shall be verified by the Air Force quality control representative. The policy further recognizes that the amount of evidence obtained or verified through product inspection will depend upon the nature and intended use of the product and the effectiveness of the contractors control over quality. This latter statement is significant in its context as a policy though frequently overlooked in the administration of the specification in the field.

Paragraph 2.10 of MIL-Q-5923 in some respects defines verifiable evidence by stating "The contractor shall maintain adequate records of inspections and tests performed. Such records shall reflect recurring discrepancies and shall contain complete information regarding corrective actions taken by the contractor. The records shall provide evidence that required inspection operations have been performed and shall indicate the number of rejections in each sample, lot, run, etc., and the reasons for such rejections. Results of interchangeability inspections and functional tests shall be indicated."

The industry feels that definite standards do exist in the MIL-Q-5923 specification for carrying out procedures such as Material Review procedures, establishment of a quality control manual, the type of records to be maintained as verifiable evidence to the Military Inspection personnel.

Efforts to adequately and properly define what constitutes suitable objective quality evidence in each case will depend greatly upon the manufacturing operations involved, the personnel, and perhaps of most importance, the attitude or philosophy of the contractor himself.

One of the major complaints in writing any specification, whether it covers the given product or is of a general nature such as MIL-Q-5923, is that the wording is indefinite and a multiplicity of interpretations can be obtained. Differences in interpretations arise not only from the complexity of the specifications and the varying degrees of experience of inspectors, but from a lack of understanding on the part of either the contractor or the procuring agency representative of the details of each procurement operation or contractual conditions. Examples of the lack of definite wording are the conception that this document must be applied in total to subcontractors and that statistical sampling could be conducted only if it was in accordance with MIL Standard 105. Subsequent adjustments to the specification wording and through directives to the field, these matters have been properly explained by the Headquarters AMC.

We feel that the Air Force specification has been somewhat weak in its definitions and clarity of the procedures for source inspection. The position of the prime contractor is well defined and the Government must hold him responsible since he is the only one with whom the Government has a contract. On the other hand, a number of statements and requirements within the specification give rise to questions of operating procedure between the prime contractor and subcontractor. This is particularly true in the cases where subcontractors produce a proprietary design article for a number of prime contractors.

The specification has been interpreted to require the prime contractor to place his own inspection personnel in subcontractors plant in order to carry out his responsibilities irrespective of government source inspection at the same facility. Also, the specification has been criticized for establishing procedures which demand that the manufacturer of proprietary articles must furnish complete engineering drawings to all prime contractors to facilitate inspection upon receipt at the prime contractors plant. It is the industry's belief that responsibility for quality control must be vested in the organization which is manufacturing the article or product exclusive of the design responsibilities, that is, proprietary or non-proprietary in nature.

Regardless of whether there is any government source inspection or not, the prime contractor must assure himself that quality control is properly administered in his subcontractor organizations. In general, however, the prime contractor will conduct his own source inspection of a resident or itinerant nature only when he finds it necessary because of the complexity of the product or processing involved.

Aside from price and technical considerations, subcontractors are selected on the basis of past performance, adequacy of facilities and procedures, and cooperative attitude. Purchase orders to subcontractors will stipulate the prime contractor or government specification requirements, including tests and inspections to be made, and the subcontractor will be asked to furnish evidence that such tests or inspections have been completed.

You may be interested to know that many of the aircraft prime contractors are currently engaged in extensive studies and compilation of product performance data from subcontractors to determine acceptable process averages which, when established, should simplify the industry surveillance problem.

There may be other reasons for a prime contractor conducting source inspection at a subcontractor's plant. For example, the inspection of certain products at source might effect considerable saving in manpower and floor space at the prime contractor's plant, even though the article being produced could be inspected at the prime contractor's plant upon receipt. Such procedures, however would not affect the basic responsibilities agreed upon with respect to the prime contractor and subcontractor quality control procedures. This type of industry source inspection would merely be for convenience.

We are pleased to find that the Air Force is adopting new plans on government source inspection, which will to a large degree complement the industry's procedures at their subcontractors' plants. The so-called automatic source inspection plan, which it is understood will be established at approximately 300 subcontractor plants serving the aeronautical industry, resident or itinerant surveillance type Air Force source inspection will in effect provide bonded stock for issue upon all articles shipped from those subcontractors. We believe the concentration of government source inspection in this manner will do much to reduce the extremely high cost and complexity of obtaining such source inspection on purchase orders at the present time.

As a result of our recent industry experience in the field of guided missiles, electronics and other contracts primarily of a research and development nature, the AIA Inspection Committee has proposed to Air Force and Navy BuAer, the adoption of a policy and specification requirements to differentiate between the type of inspection procedures necessary for research and development and production work. Our industry believes that little if any regulation over strictly research contracts is desirable and as much flexibility as possible must be permitted for use of temporary drawings, tools, fixture, etc., in experimental work leading up to production. We are advised that the Air Force now has under consideration a proposed revision "b" to MIL-Q-5923, which recognizes Phase I (Research), Phase II (Development), and Phase III (Production) and differentiates between the application of certain MIL-Q-5923 requirements for each of these phases. Discussions with industry are now being undertaken in order to develop a suitable and workable document, which can be used in part or in whole depending upon the type of contract in a given facility.

Is It Based on Practical Requirements?

A second major criteria which I have cited as being necessary for a good quality control standard concerns the use of practical product specifications. This may seem somewhat off the point of this discussion on a quality control specification but industry is governed primarily by Military product specifications defining in technical and legal fashion what performance and design features will be required. Such documents are cited in the first article of all contracts and actually set the stage for the type of quality control performance which MIL-Q-5923 says we must produce. These two contract requirements are intimately related and interdependent, and we believe that a good quality control system must be a reflection of practical, common sense easily understood product specification requirements.

Industry has long objected to military specification requirements which attempt to dictate methods and procedures for accomplishing a desired objective already stated in terms of performance in the contract guarantees. The industry's slogan has been along the lines of "Tell us what you want, when you want it, and we'll produce it". This simple statement is perhaps a crude but accurate interpretation of our free enterprise system. There are many examples to show the confusion of performance and design requirements appearing in a single military specification for a given product. In other cases such specifications reflect a very marked tendency toward the imposition of detail regulation of manufacturing processes and production methods.

If we are inclined to speak somewhat harshly of regulations and other restrictions on the manufacturer, it is not entirely what can be shown in black and white in the documents themselves. It is conceivable that at a high policy level in the Defense Department, we could wholeheartedly agree upon a given specification requirement or regulation only to find some months later that it is entirely unsatisfactory to our operations simply because of the absolutely impossible interpretation by someone down the line who is charged with the administration. What appears to be a fair and reasonable requirement is published, but on each step down the ladder it acquires twice as many new friends and new interpretations. It is, of course, not humanly possible to write requirements which are incapable of misinterpretation.

It is the opinion of our industry that a reasonable solution to the problem is to set up broad and flexible policies supported by "ground rules", which may guide the administrator in his interpretation of the policies at a higher level. We have previously recommended a set of such "ground rules" for the use of the military agencies in developing and administering specifications and they boil down pretty generally to the following major considerations:

1. Differentiate between product type specifications which contain operational characteristics desired in the product and standards or drawings which pertain to design characteristics of the product.

2. Confine specification requirements for production articles to technical requirements which can be achieved at the present state of the art, i.e., eliminate design objectives which require deviation and may unnecessarily delay completion and acceptance of contract material.

3. Simplify and reduce material and process requirements imposed upon the manufacturer. Such documents may be fine for Air Force and Navy overhaul and maintenance installations, but are not always consistent with the contractors manufacturing operations and may seriously limit his ability to produce economically and efficiently.

4. Provide recognition for alternate methods of accomplishing specific jobs where such methods or details are necessary to include in a standard.

5. Confine inspection tests to the principal product specifications rather than separate publications not readily accessible to the contractors and inspectors.

6. Establish a clear and uniform system for qualified products approval to eliminate delays in securing approval and to encourage sufficient qualified sources.

7. Eliminate insofar as possible requirements for certification of equipment and personnel by government agencies and accept wider use of certificates of compliance where necessary.

8. Establish better methods for informing the contractor what specifications are applicable.

Some of the foregoing suggestions have been accepted and are being aggressively pursued by the military services; however, there is a great deal of room for improvement. We feel that MIL-Q-5923 can only be as practical as the procurement specification which establish the contractual requirements for the product.

Does It Eliminate Duplication and Red Tape?

The third test to which we have put the MIL-Q-5923 Specification is concerned with a question of whether it contributes to the elimination of duplication and red tape. Let me say, first of all, that we feel the Air Force has done a marvelous job in consolidating the various separate directives which formerly existed throughout its organization and placing those directives in two categories, (1) those items directly affecting the contractor which are outlined in the specification, and (2) those items affecting the Air Force inspectors which are included in DOI-74-1. At the same time, we believe there is still need for weeding out certain portions of the Air Force inspectors' directives which are actually and literally interpretations of the specification. It is our belief that everything affecting the contractor, including any supplementary interpretations of the specification, should be placed in the specification itself. Properly written it should be understood by both the contractor and the inspector.

One of the most significant steps which could be taken to eliminate duplication and red tape would be to consolidate Air Force and Navy Bureau of Aeronautics' requirements for inspection in the industry. The fundamental philosophy of both the Navy's T1-48 and the Air Force's MIL-Q-5923 are the same; the only differences are those where procedural methods of accomplishing the same objective vary and where the full recognition of surveillance type inspection has not been accepted by both Services. Although there may be fundamental differences in the fiscal and auditing policies of the Bureau of Aeronautics and the Air Force, which affect procedural aspects of the inspection function, we believe such obstacles should not stand in the way of developing a joint operating specification for general aeronautical inspection requirements. I do not mean to imply that there have been serious differences in policy between the Air Force and Bureau of Aeronautics in accepting each others practices wherever the contractor was doing business with both Services. Their interchange agreement requires them to accept each others inspection performed in accordance with the procedures of the agency having cognizance at the contractor's plant. But why have two pieces of paper with two sets of forms and directives to live by when each service aspires to the same end objective? If the military is honestly interested in getting more pounds of aircraft for their dollar, we feel it is incumbent upon them to streamline, unify and simplify, their ponderous paper work and traditional form filing procedures, which are duplicated over and over again in many industrial facilities.

One of the inspection tools, which our industry admittedly has been slow in accepting for purposes of eliminating duplication has been the use of Statistical Quality Control. I say that we have been slow in accepting the use of this tool only because certain segments of our industry have not found existing sampling methods adaptable to their particular type of production. As mentioned previously, MIL-Q-5923 started out to encourage control charts and to dictate or direct the use of certain sampling methods, even though the intent was to simply recognize the philosophy of SQC wherever it might be applicable. The full acceptance of such methods throughout our industry will come only through evolution, not through direction or legislation. This is understood by the Air Force and as a result, we see a much healthier situation today with respect to investigations and studies being conducted by our various industry members to adapt the best features of SQC as an aid in their own inspection and in their source inspection subcontractors level.

In promoting the use of Statistical methods throughout the industry, our policy has been to emphasize that sampling methods for acceptance of parts can only be as reliable and as good as the methods used in production and process control. In other words, we have had to teach ourselves and our subcontractors that statistical sampling procedures can be used to eliminate duplication and expedite production only if proper and adequate procedures are established throughout the entire engineering and manufacturing functions of the company. SQC cannot be applied economically as a test at the end of the line unless full integration and understanding of the process and manufacturing controls are maintained within the plant. At the present the AIA Inspection Committee is engaged in a study of the comparative effectiveness of sampling plans for various types of product. Statistical sampling by attributes, by Lot Plot, against 100% inspection will be studied over the next six months. This method of sharing experience on a new tool for inspection, we feel, will pay dividends to both the military services and the industry, and particularly to subcontractors who will be called upon in the future to employ process control methods to make economical the statistical sampling acceptance procedures.

Does It Provide for Uniform Administrative Procedures?

Finally, we come to the fourth general test to which we have placed the MIL-Q-5923 - that of uniform administrative procedures. The specification itself does not endeavor to regulate administrative procedures, but it does define certain requirements which dictate to a large degree the type of paper work processing required by both the contractor and the field inspector. At the risk of repetition, I would like to again state that the purpose of DOI-74-1, which is the companion document to MIL-Q-5923, is good in that it endeavors to segregate those administrative procedures which affect the inspector from the contractual requirements as stated in the specification for the manufacturers. There is altogether too much material, however, in the present DOI-74-1 which is interpretative and supplementary to the specification. The contractor may read the specification and feel he understands the requirement, only to find the AF inspector has a slightly different interpretation in his book. Let's put it all in the specification if it is concerned with the contractor's obligations and what the Air Force inspector will require the contractor to perform to insure that requirements are met. Then DOI-74-1 will contain the requirements for which it was originally intended, notably such matters as leave pay, travel expense, inspectors manual, pay scales, office procedures, inspection cost control records, etc.

The industry wholeheartedly endorses the survey team procedure which the Air Force employs as supplementary to the MIL-Q-5923 Specification and the DOI-74-1 directives. We believe it to be a very healthy situation to have periodic inspection of inspectors and inspection of inspection systems. The major difficulties which we find with the present survey team procedure are not implicit with the specification by any means, but can certainly be corrected by clearer understanding on the part of contractor and the inspector of the standards which are set forth in the specification. By this, I am again referring to the need for consolidating all requirements, whether they be interpretations in DOI-74-1 or stated requirements in MIL-Q-5923, into a single and complete document read by both the contractor and the inspector. This will avoid difficulties with survey teams getting into the middle of local arguments between the inspector and the contractor. Another suggestion has been presented previously to the effect that survey teams should be made up of persons at the Headquarters level of the Air Material Command Quality Control Division and should include representatives from the district offices. In other words, the people who write the directives and specifications should get out to see how well they are working in the field.

The present system of surveillance inspection related to government source inspection requirements which are outlined in MIL-Q-5923, is not considered economical or efficient so far as the industry is concerned. A major portion of the so-called surveillance which must be maintained rests with the industry, from the prime contractor through to the third, fourth, fifth or sixth tier subcontractor level. This means a continuing attention to procedures, to certain documentation of verifiable evidence, and if kept within proper balance, such industry self-discipline can achieve the end objective. On the Air Force side of the picture, it means greater attention to personnel training and direction, employment of high caliber personnel with as broad an experience as possible and with prestige and authority necessary to carry out responsibilities. We believe MIL-Q-5923 is now written in such a manner that administration in the field could be carried out with a minimum of high caliber inspection personnel. For the larger contractors, less than half a dozen high-level experienced military personnel could conduct all of the administrative functions necessary, and for the smaller contractors or subcontractors, several high caliber inspection people in a single office could cover dozens of diversified producers. Closer liaison between headquarters and the field offices or local representatives is necessary in order to maintain uniform interpretations of MIL-Q-5923 requirements. A good many of the problems which have come up in connection with the administration of the specification could have been settled at a local level without reference to headquarters provided better indoctrination and training of the local or district people had been undertaken.

The military inspector in a contractor's plant or in a district serving many contractors should be a highly responsible and authoritative person since he is the first and usually the principal contact between the buyer and producer. Since he must operate under a rather flexible set of general rules, we feel he should be the highest type of executive personnel which the military can procure. The inability of the contractor to obtain prompt settlement of inspection problems has caused considerable concern even before the issuance of MIL-Q-5923. Though the specification has assisted in minimizing some of these problems, it must be recognized that the quality of inspection and the degree to which progress is achieved in any particular

facility is governed largely by the capabilities of the military personnel who are assigned. The inspector is often called upon to perform functions at the contractor's plant for which he is not qualified; as, for example, the approval of certain engineering changes in design. This function is not covered in the specification but is one which over the years he has been expected to undertake as service to both Air Force and contractor. If proper procedures are established for handling and implementing engineering, fiscal and related decisions, which are not properly a part of the quality control function, we feel the inspector might be able to concentrate on his duties as outlined in DOI-74-1 and the administrative functions of MIL-Q-5923.

Conclusions

I have had a great deal to say about the shortcomings of MIL-Q-5923 and not too much about the salutory effect it has had upon the industry in general. In conclusion, I would like to state that we feel the Air Force should be proud of their efforts during the past few years to establish definite standards for inspection and quality control requirements and improved administrative procedures for the Air Force inspection system. The industry has applauded these steps, including the initial development of MIL-Q-5923, and we feel that more significant advances have been made in the short span since World War II than were achieved in the 20 years previous. If I have spoken critically of certain features of MIL-Q-5923, it is not because we are in any sense opposed to its general tenor and objectives. We have appreciated the Air Force's spirit of team-work in solving the problems associated with advances in inspection policies and we feel that such team work will continue to pay off in the future. Through the medium of the AIA Inspection Committee, which was only established three short years ago, an exchange of experiences in dealing with various types of military inspection requirements has contributed in no small measure to a better understanding of both Air Force and Navy BuAer problems. We hope that this experience has also resulted in better understanding by the military of the variety and diversity of problems that exist within the industry.

THE QUALITY CONTROL ENGINEER IN THE PULP AND PAPER INDUSTRY

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In its broad sense, Quality Control is the prevention of defective manufacture, whatever methods may be used for that prevention. From this viewpoint, Quality Control in the Pulp and Paper Industry, though usually not known by that name in the past, is as old as the Industry itself. For years inspections and measurements have been made on materials, at various process stages, and on finished products. For years such inspections and measurements have of necessity been made on a sampling basis. For years the data from these inspections and measurements have been used to determine what process adjustments should be made to prevent defective manufacture. From this standpoint, any company which is competing successfully in the Industry today must have had Quality Control from the time it started its manufacturing operations, otherwise it could not compete successfully.

It is generally recognized today, however, that to continue to compete successfully in the future, "Quality Control" in the old sense is not enough; there must be a "Quality Control Program", recognized as a separate service function. The difference between "Quality Control" in the old sense and a "Quality Control Program" in the modern meaning is that the latter not only attacks day-to-day problems as they arise, but is also a coordinated service function for long-term planning. This coordination and long-term planning call for the use of certain managerial and technical skills. These skills are the basis of the Modern Quality Control movement.

The purpose of a Quality Control Program is to minimize losses due to defective manufacture. There are two general categories into which these losses fall. One is loss of good will as a result of defective product which finds its way to the customer. The other is excessive internal costs incurred to prevent this from happening, such as high rates of scrap and rework, downgrading of product, and excessive inspection costs.

In the Pulp and Paper Industry the potential value of a Quality Control Program is large. The market is extremely conscious of quality, and, as a result, internal losses incurred in trying to meet market quality are high. In addition to the many day-to-day problems, there is a gold mine of long-term process control problems to which a Quality Control Program may be dedicated.

* * * *

To gather information on the present status of and thinking about Quality Control in the Pulp and Paper Industry, a survey of the field has recently been started. The purpose of the survey is two-fold. One objective is to clarify just what is meant by a Quality Control Program in the Industry, and how it can best be organized. The second objective is to indicate the types of contributions the Quality Control Engineer can make to the progress of the Program. While the information gathered so far is comparatively meager, certain outlines are beginning to emerge. These outlines, as they appear at present, can be illustrated by describing the situation at a mythical, idealized, composite company called Quality Pulp and Paper, Inc.

Quality Pulp and Paper is a multi-plant organization with pulp mills and paper mills. At each mill there is an inspection group headed by a Quality Control Supervisor. There is a central Quality Control office occupied by the Quality Control Manager and several Quality Control Engineers. The Quality Control Supervisors and Quality Control Engineers report to the Quality Control Manager, who in turn reports to the Vice President in Charge of Manufacturing.

One important duty of the Quality Control Supervisor is to appraise the quality of the finished products shipped from the mill to which he is assigned. He keeps the Quality Control Manager continually informed of the results of such appraisals. The Quality Control Manager analyzes and condenses these appraisals, studies trends and pertinent data on customer complaints, conducts market quality surveys, etc. From such data he assembles each month a Product Quality Audit for the Vice President. In addition, any serious quality deviations are reported immediately from the Quality Control Supervisor to the Quality Control Manager to the Vice President. The purpose of this part of the program is the prevention of loss of customer good will due to defective product.

In making these finished product appraisals, the Quality Control Supervisor is essentially "detecting deviations" from quality standards.

The other duties of the Quality Control Supervisor are directed toward the objective of minimizing internal losses due to defective manufacture. In carrying out these duties, he is "detecting abnormalities" in materials, processes, and finished products. Abnormalities are immediately reported to the manufacturing personnel in order that the know-how of the foremen and operators may be put to work immediately on the problem of ferreting out and eliminating the causes.

In addition to "detecting abnormalities" the Quality Control Supervisors at Quality Pulp and Paper are constantly improving their skills in "detecting patterns of variability". Such patterns of variability, if brought to light in the early stages, are of substantial assistance to the operating know-how in finding causes. Illustrations of abnormalities are oil spots on a continuous sheet of pulp as it leaves the last roll of a dryer, and holes in a sheet of paper as it leaves the calender stack. A pattern of variability of the former would be indicated if all of the spots observed were two to three feet from the right hand edge of the sheet. A pattern of variability of the latter would be indicated if the distances between holes observed were consistently equal to the length of the wire.(1)

Quality Control Supervisors and their inspectors, however, are busy people. Patterns of variability are not always readily apparent. If the Quality Control Supervisory group devotes too much attention to detecting patterns of variability in one spot, abnormalities may be missed in other spots. When this situation develops, the Quality Control Engineers are brought in to carry on the search for patterns of variability, and the Quality Control Supervisory personnel devote such time as they can spare to assisting the Quality Control Engineers, but essentially return to their primary function of detecting deviations and abnormalities.

Thus the Quality Control Engineers at Quality Pulp and Paper are occasionally on immediate problems. Most of their time, however, is devoted

not to "abnormalities" but to "chronic" control problems. For instance, they develop and put into effect improvements in the specifications system; revise, where necessary, the procedures for cross-checks of testing instruments; improve methods of sampling to assure more accurate quality appraisals; assist in the planning, executing, and analyzing of experiments (2) for the study of cause and effect relationships, etc. In addition there emerge extended Quality Control Engineering Projects to help in solving the more difficult chronic control problems. In these projects also the technique of detecting patterns of variability is fundamental, and added to this is the search for new facts on relationships between cause and effect. From these new facts come improvements in the methods of controlling quality.

As illustrations, two Quality Control Engineering Projects, typical of those described in the survey, will be discussed.

* * * *

The first typical project discussed is the development and application of a type of multi-vari control chart and log for paper machines. It is essentially an adaptation of the multi-vari chart introduced by Seder.(3) It is designed to assist the operator in controlling the quality of the paper he makes.

In running a paper machine the operator must keep a watchful eye not only to prevent defects such as holes, spots, wrinkles, etc., but also to control simultaneously several measured characteristics, such as basis weight, mullen, porosity, tensile, tear, etc. The controlling of these several measured characteristics at the same time, many of them interrelated, has become an art of which the skilled papermaker is justifiably proud. Part of his art is to know, at any given time, whether a process adjustment is required. If it is not required, he must leave the process alone. If an adjustment is required, he must know what to adjust, when to adjust it, in what direction, and how much of an adjustment to make. He must know how long it will take the result of his adjustment to affect the quality of the finished paper. He must analyze the measurement data to see whether the process is, in fact, responding to his adjustments, and, in so doing, must look for patterns of variability in both the machine direction and cross-machine direction.

Unfortunately papermakers are not all equally skilled. There are three kinds of evidence which attest to the truth of this. First is "proof-of-the-pudding" type of evidence; the product made by some operators is less uniform than that made by others. Second is the fact that, under very similar conditions, some operators adjust their machines more frequently than others.(4) Third is the startling difference between answers given by various operators to the same question. Among questions known to have been answered quite differently are:

> "How much does a half-turn on the stock regulator affect the basis weight?"
>
> "How much does an increase of 10 amperes in the jordan affect porosity?"
>
> "How long does it take the effects of these adjustments to be complete at the dry end?"

So long as such questions are without answers as told by the processes, papermaking remains an "art". The purpose of the multi-vari chart and log is to change part of this "art" to "science". As science, the facts about cause-and-effect relationships become available to all operators, rather than being "known" only by those with long experience. The multi-vari chart and log helps to effect this change by providing several services, among which are:

1. A clear picture of the pattern of variability.

2. A continuous record of the adjustments which are made.

3. A prompt and clear picture, in terms of product quality, of how the process is responding to the adjustments.

4. Limits within which the product may be considered uniform. When variation remains within such limits, no adjustments should be made.

A typical multi-vari chart and log is shown in Figure 1. Each vertical pair of circles represents the two extremes of the three measurements taken across the sheet at the end of a reel.(5) The letters mean front (F), center (C), and back (B). An empty circle means a tie. In the actual illustration, for instance, the first entry at 5:15 means that B was in the range 160-189, and both C and F were in the range 130-159; the second entry at 5:55 means that B was in the range 190-219, F was in the range 130-159, and C was between these two; at 6:30 all three readings were in the range 160-189.

If the distance between circles on a vertical line is too great, there is excessive cross-machine variability. If there is a repetitive pattern from reel to reel (e.g., B always high) there is a repetitive pattern in the cross-machine direction. Significant variability in the machine direction is represented by significant shifts in the levels of the circles as the chart progresses from left to right.

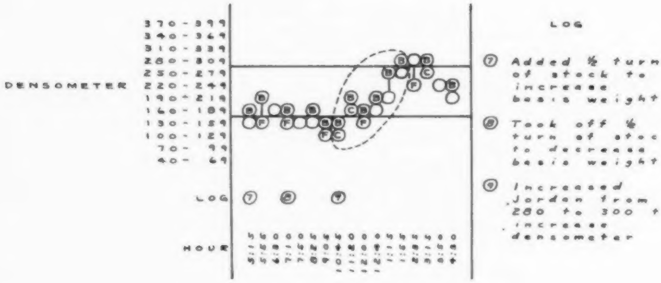

Fig. 1. Multi-Vari Chart and Log

The log of adjustments at the right is the heart of the chart. These tell specifically what is adjusted, in what direction, how far, and for what reason. By means of the number system the adjustments are coded to the chart on the reel-to-reel time scale. Thus, over a period of time, clear data may be assembled to indicate the extent and speed of the changes in finished paper characteristics which result from specific amounts of adjustment.

The chart limits apply to the <u>individual</u> measurements at the three points across the sheet. In this way a single chart indicates both range and central tendency, and avoids the misunderstandings which often develop between the statistician and production man when limits are set for <u>averages</u>. While this method loses some of the sensitivity attained when averages are plotted, experience has indicated that this is not a serious practical disadvantage. To establish the limits, the three measurements across each reel are considered as a subgroup.[6] After eliminating those subgroups in which a significantly repetitive cross-machine pattern is observed,[7] the average of the ranges of the remaining subgroups is calculated. From this, the standard deviation of individual values is computed.[8] The distance between limits on the chart is six standard deviations of individual values.

In several reported instances these charts have indicated clearly the presence of repetitive cross-machine variability which had not been observed in the mass of figures of tabulated data. They have in many instances indicated that changes in flow of stock, amount of jordan treatment, etc., start trends which last for several reels rather than taking place immediately and sharply. Thus there is evidence that paper machines have been subjected to overadjustments, resulting in a saw-tooth pattern of variability from time to time. Additional knowledge on this question should be of real value to the paper maker.

Figure 2 is a reported illustration of a repeating pattern of cross-machine variability. Figure 3 is a reported illustration of a typical instance of overadjustment.

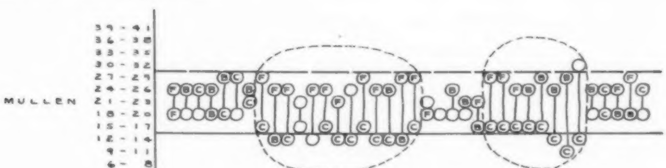

Fig. 2. Repeating Cross-Machine Variability

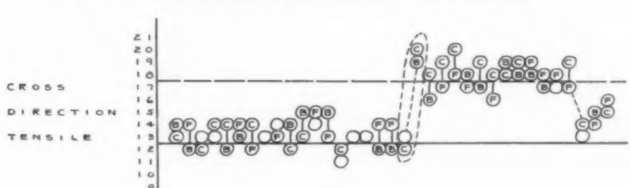

Fig. 3. Overadjustment

The second typical project discussed is the development of a series of Operating Charts for Control to help in improving uniformity of product in various process stages in the pulp mills. It is based on the technique of multiple regression.[9]

The basic questions of controlling quality are the same in the pulp mill as in any manufacturing operation. These questions, repeated again here, are:

1. Is the process in need of adjustment?

2. If so:

   (a) When should an adjustment be made?
   (b) What should be adjusted?
   (c) In what direction should it be adjusted?
   (d) How far should it be adjusted?

The answers to these questions in the pulp mill are not easy. Usually there are several factors to contend with simultaneously. A typical illustration is the ordinary chemical reaction.

Suppose, for instance, that the pulp flows continuously into a reaction tank. The chemical property to be controlled is determined by testing periodic samples of the pulp as it flows into the tank (incoming property). The object of the reaction is to raise the value of this chemical property to some desired level. How successful the reaction is in getting the property to the desired level is determined by testing periodic samples of the pulp as it flows out of the tank (outgoing property).

The four fundamental factors in such a reaction are:

(A) At what value of the property to be controlled did the pulp enter the tank? (incoming property)

(B) How long will the pulp remain in the tank?

(C) How much chemical reagent should be used?

(D) What should the reaction temperature be?

Usually factor (A) is somewhat variable; often it varies widely. Factor (B) can sometimes be controlled by the operator; more frequently it is controlled by the demands of production. Factors (C) and (D) can usually be controlled by the operator, but often with limitations dictated by the economics of the cost of reagents and heat.

To be specific, assume that (A) and (B) are not controlled by the operator, i.e., that he must take these as he finds them, but that he has control, within limits, of (C) and (D). He still has a complex problem. Knowing (A) and (B), his problem is to select values of (C) and (D) which will produce a uniform product at the desired level as it flows out of the tank.

How does he go about solving his problem? As a trained chemist, he "knows" the extent to which <u>time</u>, <u>amount of reagent</u>, and <u>temperature</u> will affect the chemical reaction. His "knowledge" may be based on published

information. Better still, his "knowledge" may be fortified by the results of experiments conducted in the laboratories of his own company, possibly even by himself. Yet he knows also that these "laboratory" results do not necessarily hold true in the "every-day pulp mill". Past data have shown him that certain departures from "theoretical" practice must be followed to secure the results he wants. Just what these departures are is not always entirely clear, and at best they seem to vary from time to time. Yet a study of past data seems useless in an attempt to clarify them, for the data appear to be hopelessly entangled, not only because of the entwining of the variability of the four "major" factors which have been mentioned, but also because of countless other factors which enter into the results and "cannot" be separated from the data.

Even if he could succeed in "knowing" the effects of each of the four major factors, he is pressed with the need for immediate decisions on the two over which he has control, and, in the pressure of the day's work, he would have to be almost a human computing machine to arrive at the optimum answers each hour during the day. He therefore simply does the best he can. If the result meets the quality requirements of the customer, all is well. If not, there is continual pressure for more uniform quality, but there is a dearth of constructive suggestions as to how it shall be attained.

In a situation of this kind the technique of multiple regression offers valuable assistance. The first step in this technique is to tabulate data from mill experience, a typical example of which is shown in Table I. In such a tabulation the outgoing property (after reaction) is matched against the corresponding values of incoming property (before reaction), time, amount of reagent used, and temperature. Due care is taken to allow for time of flow from one point to another.[10]

TABLE I

Typical Data from Mill Records

Incoming Property (A)	Reaction Time (B)	Amount of Reagent (C)	Reaction Temperature (D)	Outgoing Property (P)
47	116	.038	90	164
45	125	.030	100	161
56	118	.028	110	187
47	121	.042	85	162
55	117	.048	90	177
54	123	.050	115	197
44	119	.038	105	170
56	115	.044	105	189
51	117	.042	100	171
55	123	.046	95	182

The multiple regression technique is a mathematical procedure for processing the data in such a way that a least squares linear regression equation results. This equation expresses, as closely as a linear equation can, the outgoing property (P) as a function of the four "major"

process variables, viz.: incoming property (A), time (B), amount of reagent (C), and temperature (D); in each case showing the effect of one factor while mathematically holding the other three factors constant.

In the case of the data from Table I, the regression equation is:[11]

$$P = 4 + 1.51A + .064B + 435C + .71D$$

In addition to providing such an equation, the multiple regression technique also provides measures of:

1. The amount of variability in P which remains unexplained by variability in A, B, C, and D. If this is small, good control is within reach. If it is large, other dominant factors must be found before substantial improvements in uniformity can be attained.[12]

2. The significance of the effect of each of the tested variables (A, B, C, D) on the variability of P.

In the case of the data from Table I, only 20% of the variability in P remains unexplained by variability in A, B, C, D.[13] This is very good. Furthermore, the effect of B is without significance. This means that reaction time, within the limits to which it varies in practice, is not important[14] and need not be considered by the operator in deciding on values of C and D. Thus his problem becomes substantially simplified.[15]

Even so, the operator must still take into consideration the value of A, and from this decide on a combination of values of C and D which will yield a value of P as near as possible to the desired value. This is still not easy under the pressure of hourly duties.

The decisions can be speeded and their accuracy improved, however, by an Operating Chart for Control. The first step in making such a chart is to recalculate the regression equation, leaving out of consideration the insignificant factor B. The new equation is:

$$P = 12 + 1.47A + 419C + .72D$$

Suppose that the desired value of P is 175. Substitute this value of P:

$$175 = 12 + 1.47A + 419C + .72D$$

Solve this equation for either C or D, e.g., D:

$$D = 1.39\ (163 - 1.47A - 419C)$$

Now, replacing A and C by values selected in such a way as to cover their variation as indicated by the data, various values of D are calculated as shown in Table II. The resulting Operating Chart for Control is shown in Figure 4.

TABLE II

Calculations for Operating Chart for Control

Equation: $D = 1.39 (163 - 1.47A - 419C)$

A	C	1.47A	419C	163 - 1.47A - 419C	D
45	.030	66.2	12.6	84.2	117
55	.030	80.8	12.6	69.6	97
45	.035	66.2	14.7	82.1	114
55	.035	80.8	14.7	67.5	94
45	.040	66.2	16.8	80.0	111
55	.040	80.8	16.8	65.4	91
45	.045	66.2	18.9	77.9	108
55	.045	80.8	18.9	63.3	88
45	.050	66.2	21.0	75.8	105
55	.050	80.8	21.0	61.2	85

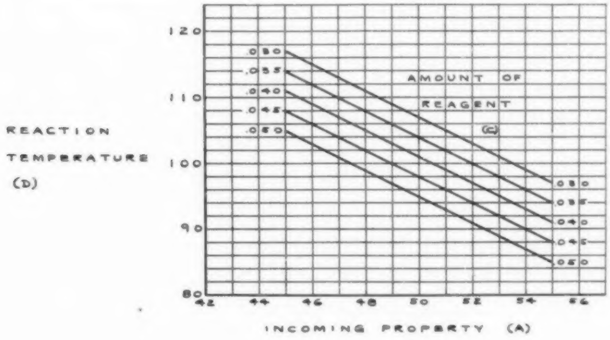

Fig. 4. Operating Chart for Control

A chart such as this can be used either to find the best temperature after amount of reagent has been decided; to find the best amount of reagent after temperature has been decided; or to make available many satisfactory combinations of the two. Such flexibility is desirable because of the many extraneous factors which affect such decisions.[16]

Example 1:	Incoming Property:	51
	Amount of Reagent:	.040
	Best Reaction Temperature:	99
Example 2:	Incoming Property:	46
	Reaction Temperature:	105
	Best Amount of Reagent:	.047
Example 3:	Incoming Property:	49

Several Temperature-Reagent Combinations:

Temperature	Reagent
97	.050
100	.045
103	.040
106	.035
109	.030

* * * *

Other Quality Control Engineering Projects of equal interest have been reported. Some of the projects reported have been brought to successful conclusions; in many others the results accomplished to date are highly promising. In some cases, however, limited success has been reported.

One prevailing difference between the favorable and unfavorable reports lies in the approach to the problem. One method of approach is "superficial", the other is "penetrating".

In the superficial approach, the attempt is made to find many places in which certain techniques, such as control charts and sampling plans, can be applied. With the effort thus applied in breadth rather than in depth, too little attention is usually given to the really serious problems of controlling quality.

In the penetrating approach, on the other hand, Quality Control does not look for places to apply techniques; it finds the places where there are serious problems of controlling quality. Having found such a place, it concentrates its efforts there, using whatever techniques it knows, learns, or can devise for uncovering new facts on cause-and-effect relationships.

The conclusion indicated is that there is an important place in the Pulp and Paper Industry for the Quality Control Engineer who has the wisdom to use the penetrating approach and the skill to follow through to successful conclusions.

References and Notes

(1) The "wire" of a Fourdrinier paper machine is an endless wire-mesh screen which travels over rollers in the direction of pulp flow and returns underneath the rollers. A dilute slush of pulp is fed onto the moving wire and the water drains through, leaving a sheet of matted pulp which passes on to rolls, dryers, etc. If there is a defect in the wire it will cause a recurring defect in the sheet, and the distance between defects will be equal to the length of the wire.

(2) Purcell, W. R. "Balancing and Randomizing in Experiments", INDUSTRIAL QUALITY CONTROL, Vol VII, No. 4, January, 1951, Pages 7-14.

(3) Seder, L. A. "Diagnosis with Diagrams", Part I, INDUSTRIAL QUALITY CONTROL, Vol VI, No. 4, January, 1950, Pages 11-19.

(4) The operators who adjust most frequently usually are not the ones who produce the most uniform product.

(5) At the dry end of the paper machine there are two rotating spindles. The finished paper is taken up on one of the spindles until enough paper has been wound to constitute a "reel" of paper. The sheet is then broken and the free end is taken up on the other spindle. Meanwhile the first reel of paper is slit and wound into rolls. Sampling at the end of each reel should be regarded as a periodic sampling of the continuous sheet; the reel end is simply a convenient time to cut samples because the sheet has to be broken anyway.

(6) The validity of using measurements across the machine as a subgroup from which to compute limits for the machine direction has been a point of controversy in the survey. The contention of those who challenge the validity of the method is that variability in the machine direction is due to causes entirely different from those affecting cross-machine variability. Those who defend the method admit that this is true as far as <u>dominant</u> (assignable) causes of variability are concerned. They point out, however, that the setting of chart limits is based on the combined effect of many <u>small</u> (chance) causes; and have submitted data indicating that these chance causes affect variability in both directions to about the same extent.

(7) The reason for eliminating such subgroups is to avoid erroneous inflation of the within-subgroup range. Such subgroups contain dominant causes of variability.

The important question is whether the variations across the sheet appear to be due to random or non-random causes. Subgroups should be eliminated from the calculation only when the repetition from reel to reel is sufficiently pronounced to yield definite evidence that is not due to chance causes.

To establish criteria for elimination of subgroups, the probability of n or more occurrences of any of three equally likely events in N chances was calculated as shown in Table III.

TABLE III

PROBABILITY THAT ANY OF THREE EQUALLY LIKELY EVENTS WILL OCCUR n OR MORE TIMES IN N CHANCES

Number of Occurrences (n)

Number of Chances (N)	2	3	4	5	6	7	8	9	10
2	.333								
3	.555	.111							
4	.703	.259	.037						
5	.802	.407	.111	.012					
6	.870	.540	.210	.045	.004				
7	.912	.649	.319	.099	.017	.001			
8	.941	.736	.428	.172	.044	.006	.000		
9	.959	.816	.540	.261	.088	.019	.002	.000	
10	.974	.857	.623	.350	.144	.042	.008	.001	.000
11	.983	.896	.701	.441	.213	.076	.019	.003	.000
12	.990	.926	.766	.527	.288	.121	.037	.008	.001
13	.995	.949	.821	.608	.369	.178	.066	.018	.003
14	.998	.965	.864	.679	.449	.242	.103	.034	.008
15	.999	.976	.897	.741	.526	.311	.150	.058	.018

Examples:

1. Four high fronts (F) in five reels:

   Probability of 4 or more = .111
   Not significant - do not eliminate.

2. Eight low centers (C) in nine reels:

   Probability of 8 or more = .002
   Significant - eliminate.

These same criteria have been used to determine whether a repetitive pattern calls for investigation and process adjustment.

(8) American War Standards. Z.1.1 - Z.1.2, 1941 GUIDE FOR QUALITY CONTROL AND CONTROL CHART METHOD OF ANALYZING DATA. American Standards Association.

(9) Ezekiel, Mordecai. METHODS OF CORRELATION ANALYSIS. John Wiley & Sons, Inc., 1950. Chapters 12 and 13. Pages 190-219.

(10) This is not an easy part of the problem. Flow is complicated by pipe friction, eddies, agitation, blending, etc., which preclude sharp identification of product. Solution of this part of the problem could well be a major project to be attacked by statisticians.

(11) Ten values of each variable are, of course, entirely inadequate for satisfactory determination of a multiple regression equation involving four independent variables. In practice most of those reporting would use about ten similar sets of data. From each set of data a set of values for the coefficients of A, B, C, and D would be determined. Thus both the average values and the variabilities of the coefficients would be indicated. One advantage in using this technique over using one hundred values for one determination is that it tests the reproducibility of the results, which should be considered in determining practical significance.

(12) Other dominant factors might be interactions between factors already considered. Such a situation calls for further extension of the multiple regression technique. For instance, see: Brownlee, K. A., INDUSTRIAL EXPERIMENTATION, Chemical Publishing Company, 1947, Page 141.

(13) This statement requires clarification. The coefficient of multiple correlation is

$$r = 0.98$$

From this, the standard error of estimate of P is

$$S_p = \sqrt{1 - r^2}\,\sigma_p$$
$$= 0.2\sigma_p$$

Thus the error of estimate of P is 20% of the standard deviation of P.

This is what is meant by the statement.

(14) As in note (11) above, this conclusion would be based not on ten values alone, but on ten analyses of ten values each.

(15) The simplification may be more fundamental and important than it seems at first glance. In one instance reported, the importance of a suspected factor had been the subject of considerable controversy. Improved control of the factor was clearly possible, but was also expensive. The comment in the ranks was: "If Management would only provide the equipment, we could control the quality". Management, on the other hand, was properly hesitant about investing in the equipment unless it could be clearly shown to be of value. A clear demonstration that variability in the suspected factor did not seriously affect product quality ended the controversy, and efforts were directed to more useful channels.

(16) Often the most important of the "extraneous" factors is cost. A simple study will usually reveal that, of several available combinations for reaching the desired quality, one does it at the least cost. Thus low cost and high quality may be made to go hand in hand.

THE NEED FOR STATISTICAL QUALITY CONTROL IN ENGINEERING EDUCATION*

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Statistical Quality Control in the large is more than control charts and acceptance sampling; it is the application of all statistical methods in the improvement of the manufacturing operation. In discussing the need for statistical quality control in engineering education I shall be using this broader definition. This in no way implies that I consider the study of the control chart and acceptance sampling techniques to be of little value to the engineer but rather indicates my belief that the engineer needs a thorough understanding of statistical principles and that the Shewhart control charts and acceptance sampling are but two of the many valuable methods of handling quantitative information which have been derived from these principles. I consider that the study of control charts and acceptance sampling provide an excellent introduction to statistical philosophy but I deplore the possibility that learning should stop without some slight acquaintance with the many other beautiful statistical tools which a considerable group of modern engineers are finding effective.

In the course of my discussion I should like to raise three closely related questions for your consideration and to enlist your aid in finding adequate answers.

Question One: "How great is the need for Statistical Quality Control in the education of the engineer?"

In spite of the fact that the American Society for Quality Control has a current membership of about five thousand and in spite of other favorable signs of growth which I shall mention later, I feel that the increase in the number of engineers who appreciate statistical principles has been painfully slow. As a result of this pessimistic attitude I find myself wondering from time to time, whether I am wrong in my conviction that any great general need exists. If time and money were available I should like to apply statistical principles in setting up an experiment to answer this question (and I believe that this should be done by some group in our society). However, for the time being, I must draw conclusions from a non-randomly selected set of references, noting that use in engineering work implies educational need.

A Bibliography of Statistical Quality Control-Supplement, compiled by G. I. Butterbaugh and published by the University of Washington Press in 1951, lists several hundred papers on statistical applications in the fields of aircraft engineering, ceramics, electrical engineering, physics, mechanical engineering, industrial engineering, naval engineering, analytical chemistry, metallurgy, and chemical engineering which have been published since 1946. In addition to those papers concerned mainly with control charts and acceptance sampling, there are many where the use of tests of significance, analysis of variance, bivariate and multiple regression,

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and rank correlation is indicated. It would be difficult to establish that the authors could not have obtained their results without the use of statistical methods but there seems to be little doubt that engineers without statistics would have difficulty in reading the papers,

In January, 1951, the American Society for Testing Materials published an ASTM Manual on Quality Control of Materials, presumably for the benefit of its membership. Presentation of data, control charts, and confidence limits are the topics covered.

Among titles listed in Movshin's bibliography section in the January, 1952, issue of Industrial Quality Control are "Microdetermination of carbon and hydrogen", "Further examination of reproducibility in chemical analysis", "Statistical analysis of blast furnace production data". The listings in other issues confirm the use of statistical methods for research and development in diverse engineering fields, and, therefore, the need for statistical education.

It seems useless to burden this paper with the weight of further evidence of this sort. It can be found by inspecting recent volumes of the official journal of almost anyone's engineering society. For example, a paper (Journal of Society of Glass Technology, Vol. 33, No. 150, February 1949) by C. E. Gould, on "The solution of the refractory blocks in the tank wall of a glass melting furnace" would prove to be unintelligible without some knowledge of statistics.

Writing on page six of their book on Methods of Operations Research (The Technology Press and John Wiley and Sons, 1951) Morse and Kimball remark,

"The final aim of operations research, of course, is to predict future operations and to understand them well enough so as to be able to modify them to produce new or better results."

(This sounds like the general aim of all engineering research)

They go on to say, "The aim is not simply to record past operations or just to explain them; in this respect the work differs from the usual statistical analysis."

(I hope that this is also one way in which statistical quality control differs from old-time statistical analysis.)

Then, on the next page, they state,

"The most important single mathematical tool of operations research is probability and statistical theory."

This statement is especially gratifying because the authors are physical scientists and a look at their bibliography suggests that they may not have been aware of all of the more recent work in statistical inference, experimental design, sequential analysis, etc., which has added so much power to the tool they commend so highly.

It is interesting to note that, during the past few years, several of the engineering societies have endorsed the existence of need for statistics by sponsoring sessions or symposia on applied statistics for the benefit of their membership. These include the American Institute of Electric Engineers, American Society for Testing Materials, American Society for Metals, the American Chemical Society, and the American Society of Mechanical Engineers.

Before leaving this question of greatness of need, I might suggest that, perhaps, the extent of the need for the statistical view-point in engineering can best be measured by the engineers themselves. Perhaps the Committee on Statistics of the University of Chicago have this in mind in establishing a program of three awards per year to holders of the doctorate or equivalent in the biological, physical and social sciences. Quoting from their announcement:

"The purpose of the Awards is to give statistical training to a few scientists who may be expected to employ it both to the direct advance of their specialties and to the enlightenment of their colleagues and students by example, by consultation, and by formal instruction. The development of the field of statistics has been so rapid that problems of communication are a serious obstacle to its full exploitation. The amount and the quality of instruction available to students are constantly increasing, but there is a real need, which these Awards seek to fill, for making appropriate instruction available to already established scientific workers who give promise of immediate applications of statistics to their special fields."

<u>Question Two</u>: <u>Why has the existence of this need been so long ignored</u>?

Dr. W. Allen Wallis, writing in the preface of <u>Techniques of Statistical Analysis</u>, published by McGraw-Hill in 1947, suggests a possible answer when he says:

"The chemical, physical and engineering sciences are on the whole, distinctly backward in the statistical planning of experiments and the analysis of empirical date ··· . No doubt this is partly because physical scientists have attained a high degree of proficiency in experimental techniques and can make repeated, independent experimental investigations of a given phenomenon ··· so that competent investigators are likely to learn the truth (though perhaps belatedly and at excessive cost) despite crudities in statistical techniques."

A somewhat different explanation is offered by Dr. Walter A. Shewhart in his 1940 address on "Contributions of Statistics to the Science of Engineering" at the University of Pennsylvania Bicentennial Conference. (Monograph B-1319, <u>Bell Telephone System Technical Publications</u>). In discussing the success of the applied scientist in contributing wonders for our enjoyment, Shewhart remarks:

"He has done much of this with a comparatively simple but extremely powerful tool, namely, scientific method based upon the concept of physical laws of nature that assume perfect or certain knowledge of a set of facts and then state exactly what will happen at any future time."

Shewhart states further,

"The fundamental difference between engineering with and without statistics boils down to the difference between the use of a scientific method based upon the concept of laws of nature that do not allow for chance or uncertainty and a scientific method based upon the laws of probability as an attribute of nature."

In many cases, engineering experimentation seems to take the following course: An experiment is conducted, a set of data is obtained, the data are summarized by computing and recording a statistic, such as the average.

The engineer does not realize, perhaps, that he has calculated a statistic because of lack of clear conception of the difference between universe and sample, parameter and statistic. Ordinarily he is content to report the value of the statistic calculated and leave to the reader the dangerous task of interpreting the experimental result. If the reader wishes to determine the limits of uncertainty for that universe parameter for which it is implied the sample statistic gives the exact value ("allowing for experimental error") he is handicapped by lack of exact definition of the universe sampled or the method of sample selection.

However, there are some extenuating circumstances because experimental results usually carry little weight until there have been further experimental verifications. A second scientist repeats the experiment and calculations, thus getting a new value for the statistic. Now we have two estimates for the parameter. If they are close together (and I confess ignorance of the objective definition of "closeness" in common usage here)—if they are "close" together, the results of the two investigations are assumed to be in agreement. The reader, at least, has a sample of two experimenters.

Many engineers have a curious attitude toward chance variation. For some reason they seem to consider its existence as an insult to engineering science. As near as I can interpret their attitude they seem to believe that scientists ought to be able to isolate the exact causes of all variation and, since this goal of perfection has not been attained, there is a certain stigma attached to the presence of variability. Therefore, as in the case of the model child who has a temporary lapse of deportment and acts like a little beast, we should politely ignore all unexplained variation and just act as though it had not happened.

There are many good engineers and scientists, however, who are not ashamed to recognize that physical constants, determined theoretically from mathematical models of idealized situations, are not constants for the hetrogeneous materials and conditions of our physical world. Since they cannot achieve complete determinism they are willing to face facts and cope with the world as it is. For example, Dr. R. M. Haward writes on page 39 of his recent book on <u>The Strength of Plastics and Glass</u>, (Cleaver-Hume Press, London, 1949),

"It is at present impossible to predict the strength of a particular piece of glass, except within very wide limits, and only the average obtained from a large number of strength measurements has real meaning. However, even an average strength figure does not alone sufficiently characterise the property measured since it is also necessary to know the degree of scatter to be expected in the results, i.e. the extent to which individual measurements are likely to depart from the mean. Thus adequate measurements of the strength of glass are inseparable from the characteristics of statistical procedure and the full implications of this variability must be appreciated before any attempt can be made to apply the conclusions reached from experimental work."

If anybody should suspect that Haward is alone in his recognition of the central role to be played by statistical principles in coping with variability or that troubles are confined to glass, he might read Chapter V of the monograph, <u>An Engineering Approach to the Selection, Evaluation and Specification of Metallic Materials</u> (Reprinted from <u>Steel</u>, November 22, 1943-February 14, 1944), prepared by Dr. H. W. Gillett, formerly Chief Technical Advisor at Battelle Memorial Institute. In his first paragraph he states that "scatter is the primary, underlying problem in the engineering use of materials" and then proceeds to illustrate how necessary the statistical view point is for the practicing engineer. Two of his many observations which I find satisfying are,

"We are often told that the polished endurance limit of a steel, determined on smooth specimens, is half the tensile strength. But when thousands of endurance tests are plotted against tensile strength as in Fig. 22, the scatter band shows that this "law" is never wholly reliable, that it becomes still less reliable above 180,000 p.s.i."

and

"The probability point of view leads to skepticism about statements in technical and advertising literature on the properties of material of a given chemical specification. Characteristic curves of tensile properties vs. tempering temperatures for various SAE steels have been published by various steel mills as guides to the user. In some cases the curves for the same SAE steel given by two producers differ more than those for two SAE steels of quite different chemistry. When scatter band curves are given instead of mere averages, these discrepancies become more understandable."

It is my considered opinion that the principal reason why the engineer has failed to recognize his need for statistics is because of this refusal to admit the existence of chance variation in nature. As long as, on the one hand, he insists on considering only "ideal" materials, and, on the other hand, is content to lump together chance variation and experimental errors, I am not optimistic about any change in his attitude toward the need for statistical methods.

Another weighty reason is, perhaps, because most engineers have not had time to find out what modern statistics has to offer. The University of Chicago announcement, along with my past experience leads me to issue this challenge to the engineer in any field: Spend one year in studying modern statistics. Try to apply the principles and methods to your own problems. Then prove publicly that your time and efforts were wasted.

Such a challenge is quite safe. Any worker in the field of engineering research, for example, will speedily become aware that in engineering experimentation, as is the case with all other types, the data observed represent a sample from a universe. He will appreciate that modern statistical inference provides the best objective methods for extracting the maximum amount of information from the sample regarding the universe which, after all, is his real interest. He will come to appreciate the truth of such a statement as that of P. O. Johnson, on page 386 of the June, 1951, issue of Scientific Monthly, when, in discussing statistics as scientific method, he says,

"Scientific method is common to all the sciences. Statistics as a branch of the scientific method provides the doctrine of the planning of experiments and collection of other types of observations, and of interpreting their consequences. This common relation to all sciences is strengthened in that statistics furnishes a common methodological basis of understanding, namely, the derivation of the best infallible inference which the experiment or other observational data possess with respect to the theory or hypothesis under examination. This means that statistics is concerned with the central problem of any scientific investigation. Further, the extent of agreement between experimental data and the assumptions is among the objective factors that govern the acceptance of solutions proposed for scientific problems. In this determination statistical procedures play a prominent part."

The engineer-statistician will find, I think, that his past idea of the nature of statistics was incomplete, if not wide of the mark, He will begin

to agree with the sub-head in Warren Weaver's beautiful article on "Statistics" in the January, 1952, issue of Scientific American, which states,

"The word usually suggests masses of numerical information, but it also describes that department of mathematics which grapples with the complexity of nature by means of samples."

I am confident he will find (to quote further remarks in Wallis' preface) that "even though sound statistical techniques may not be indispensable in the physical sciences, they are invaluable." Furthermore, by both practice and preaching, he will be a leader in spreading this gospel among his associates.

Finally, I sincerely believe that another reason the need has not been recognized is because many, if not most, of our statisticians have a less than perfect understanding of the exact nature of the important problems in the various fields of engineering. I am inclined to think that we need more statisticians who can out-engineer the engineer in solving engineering problems. That would seem to be one of the best ways of convincing him that methods of studying pigs can be applied to pig-iron.

As an illustration of success in this direction I might call attention to Miss Besse B. Day's paper on "Application of statistical methods to research and development in engineering", reprinted from the Review of the International Statistical Institute, (1949), and describing some of the work at the United States Naval Engineering Experiment Station at Annapolis. On summarizing the applications in the TV fuze program, she states:

"It was demonstrated conclusively on the fuze program that statistics was a vital tool in the solution of engineering problems of research, development and production. The head of the tube group went on record with the statement that the statistical methods had probably saved several million dollars on that project alone."

Question Three: How can this need be met?

The expected answer is: "Require each engineering student to take a course in applied statistics." Before accepting this easy answer which is, perhaps, a very good answer, let us not forget that engineering curricula are bulging at the seams. Some engineering schools have gone to a five year course, in spite of the obvious financial burden on the student and the accelerated demand to supply industry with product quickly. For the four-year courses there is a continual search to find ways to streamline curricula by deleting or reducing some of the time-honored subject matter. Anyone proposing a required course in statistical quality control should be ready to present a very strong case for dropping out a semester of calculus, or physics, or english.

Another worthy answer was that given by an educational officer to a quality control director for one of our large companies. The director of quality control visited the campus to lodge a request that the particular institution expand its statistical offering for engineers. The answer, in effect, was this: "It is expected that, in the engineering courses, the student will receive incidental training in the statistics which he needs."

This hopeful position reminded me of a former college president who usually included in his fall message to his faculty a plea to use their courses as an opportunity to teach their students to speak and write good english. I am

confident that although they recognized the importance of the request they felt nervous about complying with it very fully. I suspect, however, that the president's request did spur the professors to give more careful attention to their own use of english.

I hope the time will come when statistical principles will have their rightful place with other scientific principles in every engineering classroom and laboratory but, in working to hasten that time we must keep in mind that most engineering teachers are, themselves, the product of engineering education.

In the 1950 report of the sub-committee on College Courses, of the American Society for Quality Control, (a sub-committee for which Professor John A. Henry of the University of Illinois served as chairman), one conclusion reported was

"Industry is exerting pressure for undergraduate statistics on the engineering colleges. This pressure is honorably exerted by the attitude of recruiting personnel. This can and should be intensified by members of ASQC and their associates."

While I thoroughly approve of the general principles: "If you want this country to be different, write your Congressman" and have encouraged direct action by graduate engineers who say "This is great stuff, but why didn't we get it in college?", yet, I must admit that I have some mental reservations in view of present conditions.

I am not sure that all of our students reach, as undergraduates, the stage of maturity where they can appreciate a full course in applied statistics. Many of the current crop have difficulty in finding summer or part-time work which gives them the industrial experience necessary as the background for applications. The teacher then must play the role of a missionary who has to teach the innocents what sin is before he can convert them.

Nevertheless, it seems a mistake to send students into engineering work without some slight introduction to the elements of simple inference. This is not the appropriate place to discuss the matter in detail but two solutions might be mentioned. One possibility is to put back into college algebra courses the work on probability which has been crowded out in recent years. The other solution, to be used singly or in combination with the first solution, is to require an abbreviated course at about the junior level organized around the binomial and normal distributions and including a liberal amount of laboratory work with sampling experiments.

For graduate students in engineering and science a formal course in applied statistics should be a welcome requirement. In view of the present trend in scientific papers it is difficult to see how a program of graduate study can be comfortably pursued without some understanding of statistical principles. Such a course could be opened, also, to qualified seniors.

However, whether applied statistics be elective or required; taught to graduates or undergraduates; in credit courses, part-time courses, or in-plant courses; I believe that the members of the American Society for Quality Control and others interested in the growth of statistical quality control in engineering education have two important opportunities for service.

First they can assume part of the responsibility of making sure that the teaching is done by people who are competent both in the field of statistics

and in the field of industrial application. In my opinion it may be fully as damaging to have the teaching done by a mathematical statistician with no experience in application as by an engineer with no knowledge of statistics. If we must choose between these two alternatives, let's choose both and have the two specialists work as a team.

In a paper in the December, 1951 issue of the Journal of the American Statistical Association, on "Yates' correction and the statistician," Franz Adler has hidden the following pertinent remarks, which bear on the manifest advantages of such co-operative effort:

"The mathematical statistician can - and often does - provide logical soundness. It is the business of the research worker who applied the statistical methods to his field to report which one of alternative methods he used brought results most closely consistent with the results of his experience.

"The realities of any field are not of necessity identical or parallel to mathematical assumptions. Only in a mutual exchange of ideas and experiences between the mathematical statistician and the practical research worker can it be found which assumptions, which methods, and which procedures fit which field."

The second opportunity for service is that of contributing teaching materials. When teaching applied statistics the major portion of my time and energy is used in ferreting out appropriate problems for assignment and discussion. I must acknowledge my own gratitude and the gratitude of my students to those engineers who have supplied me with concise, but complete case studies, together with the necessary data. Some I get by begging, a few come unrequested, a limited number I am able to extract from published papers. I am not alone in needing a greater and more varied supply of standard applications. I should like to have at least one from each of the engineering fields (and most should be such that the students can do the necessary numerical work in less then one hour) Again, I think I speak for the vast majority of teachers of applied statistics. To us, it seems almost certain that, whenever, through co-operative efforts, better teaching materials become available, the need for education will be met more effectively.

Closure.

In closing this presentation and opening the paper for discussion and demolition, either oral or written, I restate the three questions at issue,

1) How great is the need for Statistical Quality Control in engineering education?

2) Why has this need been so long ignored?

3) How can this need be met?

I believe there is ample evidence that the need is great. Also I have little doubt that the need can and will be met when it is more universally recognized. It becomes of utmost importance, therefore, to investigate fully the assignable causes why this need for statistical quality control in engineering education has been so long ignored and to either counteract their effect or entirely eliminate them.

A SURVEY OF THE APPLICATION OF MIL-STD-105A IN THE AIRCRAFT AND ASSOCIATED INDUSTRIES

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On May 25, 1951 the first national meeting of the Aircraft Technical Committee was held as an adjunct to the Fifth Annual Quality Control Conference in Cleveland. One of the projects launched by the committee was a survey of Mil-Std-105A to determine whether such a standard is desirable, to what extent it is being used and whether it provides a practical tool. Such a survey was then made. Two questionaires were circulated to eighteen companies. Twelve responded to the first and eight to the second. Although the sample was small the results were highly revealing in that the respondents were leaders in their field and that they represented a cross section of the industries contributing to aircraft manufacture.

The results of this survey were published in the November, 1951 issue of Industrial Quality Control. Some little interest was indicated by the subscribers, committee members, and the Air Force and subsequently the planning committee of sixth annual Quality Control Convention extended an invitation that a report on the matter be presented to this conference as a contribution of the aircraft technical committee.

At the suggestion of the committee Chairman, Dorian Shainin, we have greatly enlarged upon our original survey to make the facts as valid as possible. Fifty companies were approached with both questionaires. Twenty-nine responded to the first and twenty-seven to the second. This response, I feel, is indeed a true measure of industries reaction to the standard as the contributers included many distinguished organizations in such fields as Airframe Manufactures, Aircraft Engine Manufactures, Electronic and Instrument Manufactures, Accessory Manufactures of all kinds, Jet Aircraft Manufactures, Jet Engine Manufacturing and propellor Manufacturers. The purpose of the first questionaire was to establish the extent of the application of Mil-Std-105A within the contributing companies.

Questions and responses to the questionaire were as follows:

Paragraph 1.1 of Mil-Std-105A reads:
"When applicable and desirable this Standard shall be referenced in the specification or contract, and provisions set forth herein shall be followed."

Q. Are you using Mil-Std-105A in the inspection of your government contract work?

A. Yes - 15
Limited application - 5
No, but planning to - 3
No and not planning to - 6

Q. Is it a requirement of your contract?
A. Yes - 9
No - 18
Optional - 2

Q. Do you find that extensive deviation from the application outlined

in the Standard is necessary in order to adapt it to your use? If so, has the government approved such deviations?

A. Yes, with government approval - 5
Yes, without government approval - 2
No - 15

It is interesting to note that 23 companies out of 29 (80%) are using or intend to use Mil-Std-105A. Six companies (20%) are not using the Standard and do not intend to use it. This proportion corresponds quite closely with the original survey. However, 60% found that it was not a requirement of their contract and most of the companies that stated it is a requirement found it so only in that Mil-Q-5923 is referenced in the contract.

Paragraph 1.5 Mil-Std-105A reads:

"Sampling plans specified in this Standard are applicable to the inspection of the end product, product in process of manufacture, or components thereof."

Q. Are you making application of Mil-Std-105A to process control through line or patrol inspection?

A. Yes - 11
No - 7

Q. If so, do such charts or records constitute adequate evidence for acceptance purposes on the part of the Military?

A. Yes - 7
No - 4

Q. Do you use it for bench inspection and final inspection of component parts?

A. Yes - 17
No - 2

Q. Do you use it for inspection and acceptance of sub-assemblies?

A. Yes - 9
No - 7
Limited - 3

Q. Do you use it for inspection and acceptance of final assemblies?

A. Yes - 5
No - 3
Plan to - 1

Of the twenty companies that have made a start, emphases seems to fall first on the bench inspection of component parts. To a lesser degree application is being made to inspection of sub-assemblies and line inspection. However, in both instances over 50% of the companies were using such an application. A highly significant point is the fact that not only is a wide application being made to patrol inspection but that such charts are viewed as adequate evidence for acceptance purposes by the airforce in over half of the companies making such an application.

Fewer applications are being made to acceptance of Final assemblies but even here 25% of all the companies using Mil-Std-105A are applying it to acceptance of final assemblies.

Classification of defects has always been one of the most controversial points about the standard. The objection was not with the principle of classification of defects but in the time and effort to set up and maintain such a system. This latest survey indicates that resistance to this feature has diminished with 59% of all contributers (17 companies) having made a classification of defects and another 14% (4 Companies) expecting to.

Some companies have acknowledged a distinct practical advantage in classification of defects as an aid to inspection.

The earlier survey indicated a general favorable response to the desirability of standardization of sampling methods. The answers to this question certainly substantiate that indication.

Q. When the current national emergency ends, would you welcome a continuation of such standardization on an industry wide bases?

A. Yes - 17
Yes with reservations - 6
No - 2
Undecided - 1
No Comment - 2

Furthermore confidence is expressed in the sampling plans in response to this question.

Q. Are you using these sampling plans on any of your commercial products?

A. Yes - 16
Expect to - 1
No - 4

Questionaire I forcefully revealed that almost all the contributors have accepted and are using sampling inspection in one form or another. Of the six companies that are not using Mil-Std-105A and are not planning to use it, three are using Dodge-Romig tables in preference, and one is using an acceptance plan by variables. Only two companies are not using sampling in any orthodox form.

There is a general feeling that if sampling is going to prevail through out industry a common criterion should be used on a wide scale, especially where vendor - buyer, and sub-contractor-prime contractor relationships exist. Is Mil-Std-105A the common denominator we are seeking? Some say no, very few say yes without qualifications, a great many say yes with the stipulation that sweeping revisions would have to be made. Questionaire II underlines the reasons for this preponderance of opinion. The purpose of questionaire II was to establish the practability of various requirements of Mil-Std-105A.

The following questions were asked.

Q. Are you using or do you anticipate the use of the type of evaluation described in paragraph 3.3 (defects per hundred units)?

A. Yes - 5
No - 19
Expect to -2

Paragraph 4.2 states that the particular AQL values to be used for a given product shall be specified by the government.

Q. Has the government specified standard AQL's applicable to each of the respective classifications of defects?

A. Yes - 8
No - 18

Q. If so what are the standard AQL values?

A. Company #1

Critical	0% to .65%	AQL
Major	1% to 1.5%	"
Minor "A"	2.5% to 4%	"

Company #2

Critical	100% inspection	
Major	1%	AQL
Minor A	2.5%	"
Minor B	6.5%	"

Company #3
Various

Company #4

Critical	100% inspection	
Major	1.5%	AQL
Minor	4%	"

Company #5

Critical	0%	AQL
Major	1%	"
Minor A	2.5%	"
Minor B	6.5%	"

Company #6

Critical	100%	AQL
Major	1.0%	"
Minor A	2.5%	"
Minor B	6.5%	"

Company #7

Critical	100% inspection	
Major	6.5%	AQL
Minor A	2.5%	"
Minor B	.65% (Level I reduced)	

Company #8

Major	1%-1½%	AQL
Minor A	1½%-2½%	"
Minor B	4%-10%	"

Q. Do you find it practical in all cases to perform to requirements set forth in paragraph 5.1.1 formation of lots?

A. Yes - 18
   No - 10

Q. The computation of process average set forth in paragraph 8.1 requires that ten consecutive lots be the basis for the estimate. Do you follow this practice and find it practical to do so?

A. No - 15
   Yes - 4
   When Practical - 4

Paragraph 9.1 states that the government shall determine whether normal, tightened, or reduced inspection will be used with respect to the products submitted by a particular supplier.

Q. At present, under which of these headings does the bulk of your inspection proceed?

A. Normal - 21
   Tightened - 2
   All levels - 1
   100% insp. - 1

Q. At the start of the contract which one of these levels was specified?

A. Normal - 15
   Tightened - 2
   100% insp. - 1
   Not specified - 7

Q. Under section 9 do you generally agree with the mechanics as stated for tightening and reducing inspection?

A. Yes - 20
   No - 3
   No Comment - 2

Q. Do you consider Mil-Std-105A adequate as an inspection criteria for your product?

A. Adequate - 13
   Receiving Insp. only - 2
   To lenient - 7
   To severe - 2

The statements that qualified the answers to the questions were in themselves revealing. It will be noted that although twenty-three companies are using or intend to use Mil-Std-105A, only in eight companies has the airforce specified AQL values for the classification. In fact in some organizations the Airforce representatives at the local level are more ignorant of the requirements of the Airforce policy group and the fundamentals of sampling inspection than the contractor who looks to them for information and guidance. Be that as it may one must realize that an organization as vast as the Airforce procurement agency has its training problems also.

The Airforce is taking positive action to remedy this situation and I have always found the supervisory Airforce Personnel entirely open minded

when problems concerning procedures have arisen.

A more perplexing problem, is the variation in understanding and interpretation between the inspectors at the local level who are in different governmental services, (Navy, Quartermaster Corp, etc.). Occasionally, where goods are exchanged between plants that are under cognizance of different governmental groups this variation becomes strikingly apparent. I know of no instance where this condition has seriously disrupted the progress of work but it illustrates the point that successful application of this standard is not incumbent on the contractors alone.

There are several requirements of the standard that make it adminstratively awkward if they are adhered to. More often than not they are ignored by the Airforce Representatives and the contractors, alike. One such requirement is the computation of process average on the basis of ten lots of material. In too many instances it would take months even quite often over a year to process and inspect ten lots of a given part. This passage of time and the sporatic gathering of such data on hundreds of different parts make this requirement an administrative impossibility.

Furthermore, why is it necessary to cope with a complex scheme of AQL's, Inspection Levels (I, II, III) and stringency of Inspection (Tightened, Reduced, and Normal) to establish which sampling plan is applicable in a given instance. A lot that is a given percent defective when submitted to a given sampling plan has a probability of acceptance as illustrated by the Operating Characteristic Curve for that sampling plan. If a set of sampling tables renders good protection at normal inspection why is it less useable if lots are exceedingly good or exceedingly bad.

AQL is itself a deceptive reference. It simply means that lots of AQL percent defective will be accepted 80% or more of the time when submitted to the appropriate sampling plan in Mil-Std-105A. The value AOQL (average outgoing quality limit) as appeared in the old Jan-Std-105 was a far more relevant way of designating sampling plans.

That the standard is a highly useable tool in spite of these encumberances is evident from the survey. The majority of the companies carry on at Normal Inspection, Level II. More than half of the companies where it is in use feel that the standard gives adequate protection. Only two felt that it was unduely severe.

The advent of World War II and events that followed which gave such impetus to Statistical Methods is primarily responsible for the development of Mil-Std-105A and its predecessors. Recognizing the economy and good practice of sampling inspection the government had to find a discriminating standard under which its gigantic procurement program could function. Since no group in industry had at that time given its endorsement to any particular set of tables the government understandably designed its own. They perhaps would have done so anyway but a crystallization of industries opinion at that time may have resulted in a standard mutually acceptable to government and industry to a greater degree.

Mil-Std-105A is now an accomplished fact which the government is asking industry to accept and assimilate. The American Society for Quality Control now exists and is well qualified to voice the view of industry. This survey is a sounding board of opinion in that respect. It indicates that in its present form Mil-Std-105A does not provide a universally

acceptable criterian to which contributing companies would adhere on a long range industry wide basis unless considerable latitude in adaptation and modification at the local level were permitted. If this is the case the standard should be so amended.

A second alternative in this regard would be a conference between representatives of industry and government which would result in a revised standard that both could readily endorse.

It is often the practice of national societies to foster standard methods which will benefit industry as a whole. If Mil-Std-105A is not the standard sampling practice by attributes which will fulfill the demand for a universally acceptable criterion of this nature and no modification of Mil-Std-105A is forth coming, it is entirely, within the good offices of this society to develop and endorse such a standard. A standard, statistically sound and founded upon the day to day administrative realities of industry.

EARLY DEVELOPMENT OF THE
STATISTICAL METHOD OF SAMPLING IN INDUSTRY

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Within the past 30 years science and industry in the United States have shown a greatly expanded interest in the statistical method of controlling quality. The application of the principles of probability to relatively small quantities of observed data has found general acceptance among scientists and engineers and, more recently, among manufacturing executive and operating personnel. This widened interest is reflected in the extraordinary growth in the membership of your Society, which has indeed been most fortunate in the high caliber and zeal of its founders and officers, enabling the Society in a short span of years to take its place with the other great engineering societies as a potent influence in our economic development.

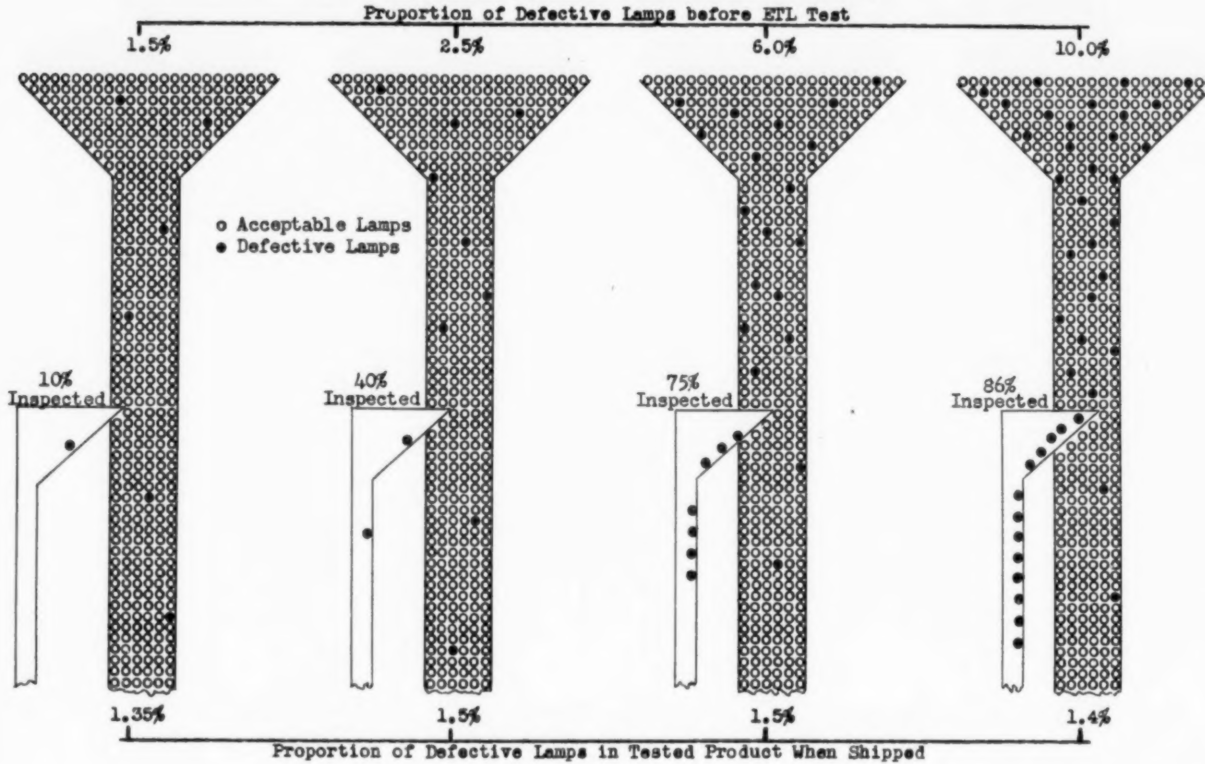
During the past 56 years ETL has been engaged in making tests and inspections of a variety of products, chiefly those associated with the electrical industry. In the earlier years most of our work was performed for purchasers, but services rendered to both large and small manufacturers of electrical products now form a major part of our business. While the experience of the author lies mainly in the field of tests and inspections of incandescent and fluorescent lamps, this paper is based upon ETL experience with a wide range of products.

In the July 1951 issue of your Journal, Mr. E. C. Molina(1) presented an outline of the early application of probability theory in the Bell Telephone System. Quite independently, beginning in 1914, some of us who at that time were engaged in inspections and tests of electrical products, similarly initiated sampling methods which recognized some of the principles involved and these were also designed to limit the proportions of defective units shipped. In this paper the author will attempt to trace briefly the stages by which statistical methods have been developed in some of our testing activities, not alone in the inspection of finished products, but also in the evaluation of product performance.

The past 40 years have witnessed a revolution in methods of manufacture. Most of the operations of assembling parts were originally performed by operators whose manual dexterity and intelligence were the prime factors in controlling quality. With the introduction of various types of automatic machinery, the control of quality passed very largely from the operators to the engineers and mechanical personnel. Industry has now arrived at another period of transition, substituting for the machine plus an operator, fully automatic production with automatic controls. Some industries have already advanced quite far in that direction.

When the electrical industry was in its infancy, factory final inspectors made a 100 per cent inspection of finished product, and this often was supplemented by purchasers' inspections, either on a periodic or continuing basis. At that time ETL represented a group of large purchasers and we made standard initial samplings, at different rates for each type of product, accepting or rejecting each batch of cable, lamps, insulators, etc on the basis of the findings in the original sample. Subsequently, beginning in 1915, the inspection system was altered to provide for second samplings of such magnitude as would reduce the proportion of defects in lots shipped, to a maximum of 1.5 per cent. Fig. 1 is a reproduction of the 1915 sampling chart for lamps, illustrating that practice.

Fig.1 - ETL VARIABLE SAMPLING OF LAMP PRODUCTS - 1915



One year later the procedure was modified to provide two sampling rates, one for serious defects (including breakage) and another for total defects. Thus the proportion of serious defects shipped was limited to 0.75 per cent and that for total defects to 1.5 per cent. Shortly thereafter an evaluation factor was adopted for each individual defect, and a sampling curve was devised which was based upon the evaluation of defects present in the initial 10 per cent sample. The limit was a reduction in value of the sampled product, amounting to one per cent.

In 1919 the author became interested in the possibility of applying the probability theory to the determination of errors involved in sampling results. This study resulted in a paper written in 1920, entitled "Sampling for Test Purposes" for presentation at the annual meeting of ETL inspectors, and it subsequently was published in the General Electric Review for June 1922.

In a very elementary way, attention was directed to the possible errors involved in findings with five, ten and twenty per cent samplings, and a general formula was devised for computing the probabilities under various sampling plans. This formula, which has since appeared in several papers and books, was as follows:

$$\text{Equation A - Probability} = \frac{C^{N-D}_{n-r}\, C^{D}_{r}}{C^{N}_{n}}$$

where: N = number of units in product
n = " " " sampled
D = " " defects in N
r = " " " in n

At first we used the letter P to denote the number of units in the entire product, but in later work the letter N was substituted.

Table I is reproduced in part from the original paper and shows the computed probabilities of finding various numbers of defects in five and ten per cent samplings of products of two sizes. These results were obtained by the laborious method of adding columns of logarithms and subtracting other columns of logarithms in order to sum up the various factorials involved in equation A above. The original table did not show the probabilities of finding no defects, but these have been added.

Table I

Probability of Finding Defective Units in 100 and 1000 Unit Products With Various Proportions of Sampling

Defective Units in Product No.	Defective Units in Product %	Per cent Sampled	Probability of finding indicated number of defects: 0	1	2	3	4	5	6	7
			100 Units in Product							
3	3.0	10	0.724	0.250	0.025	0.001				
		5	0.854	0.139	0.006	0.000+				
5	5.0	10	0.577	0.345	0.071	0.006	0.000+	0.000+		
		5	0.766	0.213	0.019	0.001	0.000+	0.000+		
			1000 Units in Product							
2	0.2	10	0.810	0.180	0.010					
		5	0.903	0.095	0.002					
4	0.4	10	0.653	0.294	0.048	0.004	0.001			
		5	0.814	0.172	0.013	0.000+	0.000+			
10	1.0	10	0.348	0.385	0.196	0.057	0.011	0.000+	0.000+	0.000+
		5	0.600	0.313	0.074	0.010	0.001	0.000+	0.000+	0.000+
20	2.0	10	0.119	0.273	0.286	0.192	0.089	0.031	0.008	0.000+
		5	0.351	0.385	0.189	0.059	0.013	0.002	0.000+	0.000+
30	3.0	10	0.042	0.139	0.228	0.238	0.182	0.104	0.046	0.014
		5	0.204	0.345	0.264	0.128	0.044	0.012	0.002	0.000+

In 1924 my associate, Mr. S. McK. Gray (2), devised a simplified approximation equation, which in general furnishes results which are accurate within less than one per cent. Here instead of dealing with 50 or 60 logarithms we have but one quarter as many for a comparable situation. This equation is shown here as a useful tool where large productions and relatively large numbers of defects are involved. The Poisson series is used quite generally for the same purpose.

Equation B - $\log_{10}$ Pr (approximately) =

$$\log (N-D)^{N-D} + \log (N-n)^{N-n} + \log e^{r} + \log D$$
$$+ \log (D-1) \ldots\ldots + \log (D-r+1) + \log n$$
$$+ \log (n-1) \ldots\ldots + \log (n-r+1)$$
$$- \log (N-D-n+r)^{N-D-n+r} - \log N^{N} - \log \underline{|r}$$

In the course of the original investigation 5000 tags, some identified in the known proportions, with defect symbols, were subjected to five, ten and twenty per cent samplings. The results were tabulated and averaged for each sampling ratio. The results were compared with computed theoretical per cent deviations and found to be in good agreement. The principal conclusion drawn from this experiment was that, with equal numbers of defects present, a given per cent sampling of a large production will yield more accurate results than the same per cent sampling of a small production.

It is generally regarded as axiomatic that you cannot inspect quality into the finished product, therefore a major part of quality control programs must be devoted to inspections and tests of component parts before assembly. In most products there are a number of component parts, each subject to variations. Further, the use of automatic machines imposes definite limits upon the tolerances for each component. The inspection of finished product is mainly for the purpose of ascertaining whether the processes of assembly have been completed in the prescribed manner.

A good quality control program is one designed to furnish reliable information very promptly to the operating force so that corrections may be effected at the earliest possible moment, and second, to accumulate data which can be analyzed for trends and improvements by the development and engineering staffs. If inspections are operated continuously on large scale production a low initial sampling rate will suffice, provided that it is supplemented immediately by second samplings when the initial sampling discloses any unusual condition.

The mathematics of first and second samplings have been adequately covered elsewhere; however, it may be helpful to point out that the inspection rate and the time consumed in recording and interpreting inspection findings can be facilitated through the use of defect symbols instead of describing defects with words. The Dewey system can be readily adapted for this purpose to any product with a number of component parts and a variety of possible defects. If a three-digit number is used for each defect, the first digit identifies the part involved, the second may indicate the degree or seriousness and the third the particular defect present. It is surprising how quickly plant engineers, foremen and operators learn to use this kind of inspection short-hand.

As early as 1923 our annual report to a group of clients stressed the need for a good quality control program to insure uniformity of the finished product. Fortunately, by that time college trained engineers were no longer confined to research and development laboratories, but were beginning to fill responsible positions in the mass production of all kinds of products. Thus the addition of technically trained men had a marked influence on precision manufacture and paved the way for the adoption of quality control based upon scientific knowledge and applied mathematics.

In one of Dr. Shewhart's books (3) he has emphasized the point that the three steps in the quality control method - specification, production, inspection - constitute a dynamic process for acquiring knowledge and, in mass production, provide a self-corrective method for utilizing raw material to the best advantage. This concept leads quite naturally to consideration of the importance of time as a fourth dimension in quality control systems. In testing work, both in factories and at the Laboratories, experience has proved the necessity for considering time, not alone with respect to its influence on the representative character of samples, but also in establishing test procedures and in evaluating test results.

For example, if a plant is operating twenty-four hours per day, suitably spaced selections will yield representative samples. However, for many types of products, if a plant is shut down eight or more hours per day, the timing of the sampling pattern must needs be planned carefully to avoid distorted test results.

In some purchase specifications, test procedure is outlined quite definitely with respect to the function of time in appraising quality and this implies the necessity for providing accurate timing devices ranging from oscilloscopes fitted with cameras, to standard pendulum clocks, adjusted precisely to Naval Observatory signals.

Let us pursue the matter of test equipment and test procedure a little further. It is obvious that the validity of the results of any quality control system rests fundamentally upon the precision of the measuring devices employed and the suitability of the test procedure. The choice of both in any specific field must be based on both knowledge and experience. Thus, a type of voltmeter that is adequate for one type of test may lead to erroneous conclusions if employed in another kind of investigation.

Large organizations engaged in mass production, usually maintain primary and secondary standards, the latter to be used in periodic checks of the measuring devices utilized at factories in the accumulation of quality control data. It is our experience that test equipment in factories requires frequent checking because of the limited knowledge of the personnel and the less expert manipulation of devices. It is important that such checks be made according to a carefully planned schedule and that worn or damaged equipment be replaced promptly.

The evaluation of the quality of most electrical products is based on three factors: Freedom from defects, conformity of initial rating with design, and performance under specified conditions. These attributes are recognized in the Federal Specifications for electric lamps and tolerances are provided for each of them.

The Federal Specification (4) for incandescent lamps for many years has been written through consultation between representatives of the National Bureau of Standards, the lamp manufacturers, ETL and others. As early as 1921 the errors involved in small samplings were recognized and life tolerances based upon sigma limits were incorporated. This table of tolerances has appeared regularly in the Federal Specification ever since that year. In fact, we believe it is the first purchase specification in which such provision was made.

Table II
Federal Specification Life Tolerances

Number of lamps averaged	Allowable per cent variation from rated life	Number of lamps averaged	Allowable per cent variation from rated life	Number of lamps averaged	Allowable per cent variation from rated life
250 and above	5	24-20	12	9	19
249-100	6	19-18	13	8	20
99-55	7	17-16	14	7	21
54-45	8	15-14	15	6	23
44-35	9	13-12	16	5	25
34-30	10	11	17		
29-25	11	10	18		

A review of various types of available purchase specifications indicates that most of them should be revised to provide tolerances based on sigma limits, thus affording the necessary latitude where small samplings are involved.

One of the problems facing industry is the need for educating representatives of medium and small purchasers in an appreciation of the range of possible error involved in tests of single or infrequent small samplings. These inherent errors may be augmented by inaccurate measuring devices, improper test procedure and unstable test conditions. This is particularly true in the evaluation of product performance, where several variables are inter-related and the incorrect appraisal of even one of them will result in a seriously distorted conclusion.

Since the average person acquires knowledge most readily through pictures, graphs and charts, it would seem desirable to disseminate widely a series of illustrations, derived from actual data, building from the result obtained from a single small sampling to the final correct average and distribution derived from many consecutive small samplings over a considerable period of time. Such a presentation might well include a section devoted to the interpretation of test data with respect to variations of each characteristic from design average. Some manufacturers have already developed material of this sort which has been distributed to their engineering and sales organizations, but these expositions have had relatively limited circulation. Therefore it is respectfully suggested that a pamphlet, prepared and sponsored by your Society, concerning these and related topics, would be influential in conveying the facts to the public in an impartial manner. Such a publication would be quite useful to manufacturers, testing agencies, technical schools and to Government procurement departments.

In conclusion the author wishes to pay tribute to Dr. Shewhart and his associates who have not only made profound studies of the mathematics underlying statistical control procedures but who have disseminated widely the results of their investigations during the past thirty years. Their introduction of quality control charts and tables has supplied the needed tools for the practical application of the statistical method and the means for obtaining economical control of quality.

References:

(1) E. C. Molina - Some Antecedents of Quality Control.

(2) S. McKay Gray - Now with Sylvania Electric Products Inc.

(3) Dr. W. A. Shewhart - Statistical Method from the Viewpoint of Quality Control.

(4) Federal Specifications W-L-101e.

"THE OPERATOR IS INTERESTED"

J. Frederick Verigan
Atlas Powder Company

I was greatly pleased when Dr. Martin Brumbaugh suggested that I discuss with you the problem of interesting the operator in quality control. Personally, I know of no subject which should stand higher on the agenda of "musts" for the quality control engineer. Those men who have had wide experience in the installation of quality control programs and their administration all agree that it is essential to have the operator's interest. The literature abounds with discussions of statistical techniques applied to our field of quality control and the newly appointed quality control engineer can find many articles on practically every one of these techniques. I am not so sure that he will find much literature warning him of the pitfall of operator's interest and giving him some methods to help overcome this obstacle. In fact, I searched through the volumes of "Industrial Quality Control" from September, 1944 until the present date and found only one article (1) whose entire purpose was to discuss this subject. This paper, by A. H. Becker entitled "Operator Interest and Cooperation in Statistical Quality Control", points out some answers to this knotty problem. Admittedly, I may have overlooked a few papers, but the fact remains that the problem has not had the publicity it rightly deserves.

The importance of this problem cannot be stressed too much. In my own experience and in the experience of many of my colleagues in this field, we have seen many quality control programs either fail to get started or grind to a stand-still. This was not due to any lack of technical knowledge on the part of the quality control engineer but was due to the fact that, for some reason or other, the operator's interest and cooperation in the program was not obtained. This has been well pointed out in the above paper (1). In many cases no effort was made to arouse their interest, while in other cases the efforts made did not achieve the desired end. Make no mistake about it, the operator himself can "foul up" the best prepared program, if for some reason he is not in sympathy with it. I have never seen a program or system that, given a little time, the operator could not beat if he is so minded. It then appears essential that, by some means, we establish the operator on our side of the fence. It is the purpose of this paper to try to accumulate and discuss some of the methods which some of my friends and I have found to be successful in obtaining the interest of the operator.

Before discussing ways and means of interesting the operator, perhaps we should take a few minutes to look at the operator himself. I would like to restate the subject, "The Operator <u>Is</u> Interested", as a statement of fact. I believe the operator is interested -- in quality control or any other method which will improve his standing, financially or otherwise. Therefore, our problem is to so point all our methods that they emphasize this aspect.

Much has been said about the modern operator being interested only in the number of pieces produced and that his pride in quality workmanship is gone. I do not subscribe totally to this viewpoint. While some operators may be interested only in the pay check (and quality control can be of interest in this way too), I do not think this is true of the majority of

machine operators. Perhaps we have "missed the boat" by assuming that this was true of all operators. Pride of a job well done is not confined to any level of achievement, and you will find just as many machine operators who have a high degree of pride in their workmanship, as in any other industrial class. The methods of interesting the operator which emphasize pride of quality workmanship will produce results with this group and to this group of operators, quality control has a lot to offer. Its methods enable management to recognize those operators producing high quality and to reward them with better positions, etc.

The other group, those operators who are interested only in the pay check can also be definitely interested. Admittedly, it may require more effort and ingenuity but it can be done. Quality control does result in machine downtime being reduced. This means more pieces produced, thus more money for the operator in those plants which are operated on an incentive basis. If the operators you are dealing with fall into this category, there are some techniques for interesting them.

Both of these groups may display a disinterested attitude at first because they are suspicious of anything they don't understand. Unfortunately, they have also been led to believe by some misguided leaders that all new tools of management are restrictive in nature and have as their goal a reduction in the pay check. Only by patient and well planned programs can these suspicions be allayed. Once this is done, however, I believe you will find the operator is interested in quality control.

It may be that I am mistaken, but I believe all methods of interesting operators need to be directed to (1) Overcome the suspicions of new management tools; (2) Appeal to the operator's pride in producing quality product; and (3) Convince the individual who is only interested in the pay check that quality control can also benefit him.

Keeping these aims in mind, let us look into some methods which have been successfully used to arouse operators' interest and to obtain their active cooperation in quality control programs. These ideas are not discussed necessarily in their order of importance. Likewise, it is not claimed that this list, by any means, includes all such methods. It should be realized, of course, that what works in some plants may not work in others. It is hoped that these thoughts will be of assistance in their present form but, above all, that they will stimulate thinking and discussion on this subject.

UNION INFLUENCE

It is unfortunately, true that, in many plants, operators form their opinion of new management tools from the attitude of union officials toward these tools. It is imperative, then, that every means be taken to see that the union officials are advised of the aims of the programs and its effect upon the individual operator. It is necessary that they understand the way the program will be organized and administered so that they can answer the inevitable questions of their constituents. The better the union officials are informed concerning your program, the more influence they can wield for you. Make no mistake. If this step attains the desired results, the odds in favor of the success of your program are greatly increased.

As a starting point, a meeting can be held at which the officers of the union, the officials of the company, and the quality control engineer are present. At such a meeting, it is good practice to have the company officials explain the need of quality control, its effect upon job security, the company's plans for administration in detail, how the quality control engineers or inspectors will function, their responsibility, etc. The quality control engineer should explain in simple terms, and I emphasize simple terms, the basic principles of quality control, etc. At a meeting of this sort, the union representatives should be encouraged to ask questions. Every effort should be made to win them as active partners in the venture. At one such meeting at which I was present, the union president asked if we would prepare a short article, for distribution to his stewards, that would explain the program. We prepared a one-page article which was distributed and which permitted the stewards to successfully answer the questions the constituents asked of them. At this plant, moves such as this assured the union of our sincerity and we did gain their active cooperation. Whenever this hurdle can be successfully overcome, the program is off to a good start.

PERSONAL TALK WITH OPERATOR

I know of no method which will produce such satisfying and lasting results as a personal talk with the operator or operators in whose area the program is to be started. The attitude of the quality control engineer should be friendly and on a common basis, not one of condescension. The aims and purposes of the program should be explained in very simple terms, being careful to keep the emphasis on the benefits which the program will give to the operator individually. I want to emphasize keeping the language simple and in shop talk. Do not try to impress the operator with your knowlege of statistics by high sounding technical language. Emphasize that control charts measure the process, its variability and level, etc. and that you are interested primarily in quality. For some reason, many operators associate these techniques with time-study. You all know what operators think of time-study, so do all you can to change this concept. In these contacts, do all you can to sell yourself personally. The more the operator is convinced of your fairness, honesty and sincerity, the more he will think of the program you are starting. Be patient, going over the details of the program which affect the operator until you are sure he has gotten the points you are trying to establish.

Once you have explained the purposes and benefits of the program, ask his opinion on the particular operation involved. Each machine operator knows considerably more concerning the eccentricites of his machine or operation than you do. He has definite ideas as to what the sources of trouble are, and how he would correct them. Listen carefully and with an open mind! In my experience, these talks can supply you with a gold mine of information on assignable causes of trouble. Don't sell any of these operators' ideas short. Prove your sincerity by getting these ideas tried. Demonstrate to the operator that the use of control charts will either prove or disprove the worth of an idea. If any of the ideas are worthy, see that the operator gets credit. If you go about these personal contacts in the right manner, you will have established yourself and your program with this one operator or group of operators. This being accomplished there will be no better testimonial for your program than from these well-satisfied operators. They will make the expanding of your program easy.

I personally know of one program where, on the initial installation, at least two troublesome sources of variation were disclosed to quality control engineers by the operators during these personal talks. The removal of these causes saved many dollars and made possible the production of a high quality item.

MAKE THE OPERATOR A PARTNER

Most of the machine operators I have met are intelligent persons with at least the average amount of curiosity. They would like to be an active participant in any new project and they will usually respond if they are invited to take part in your program. For one reason, it makes they seem to be just a little more on the inside of this new venture than the other operators.

It is not difficult to teach an operator to make the necessary calculations and plot values on a control chart. Take the time to teach him, and ask him to maintain the chart for you. As the points progress across the chart, interpret the chart for him in simple language, point out how the chart responds to tool wear, tool adjustments, changes in stock, etc. Unless he is different than the majority, you will have a very interested partner in your program ere a few days have passed and he will have a great influence over the balance of the operators in the department.

As an illustration of what can result from this approach, I should like to recount an experience of which I was privileged to be a part. It had been decided to apply statistical quality control to a branch plant which produced screw machine parts. We decided to carefully select two machines and seek the cooperation of the two operators on each shift. They were taken to the Superintendent's office where the engineer explained the purpose of quality control, what we hoped to gain at this plant, and gave a little idea of how it worked. The Superintendent emphasized that these men had been hand-picked because of their acceptance of progressive ideas, pride in their work and good spirit of cooperation. They agreed to become partners in the program. They were given 10 hours of instruction in the mechanics of constructing and maintaining a chart. The charts were started. At this point we agreed we would let these charts run for a month to obtain the reaction of the remainder of the employees before expanding, and so I returned to the main plant.

The next week as I made a visit to the branch plant, imagine my surprise to find several dozen control charts upon machines. Upon questioning, I found that other operators had been so curious as to the control charts, and so anxious that the two selected operators should not get ahead of them, that they had requested the two selected operators to instruct them how to make a chart. There were many mistakes, of course but, because of the competitive spirit of these operators, we were forced to take the entire force in groups of 20 and teach them to maintain control charts. The entire shop was placed under quality control six months earlier than we calculated in our most optimistic estimate.

Perhaps this is one of those things that happens only once in each quality control man's life. I do believe it shows what can happen by the careful selection of the operator and by taking him in as an active partner in the program.

IMPROVED GAGING METHODS

In addition to improved gaging methods being a requirement for statistical quality control, it is also a means of interesting the operator. He realizes that better equipment permits him to produce quality parts with more assurance. He is usually interested from a personal standpoint, in having the latest type of equipment to work with. When the new gage is placed into operation at the machine, the quality control engineer should take that opportunity to describe its benefits to the operator. In most cases it will be some type of direct reading gage replacing a go, not-go type. It is not difficult for the operator to see that this new gage gives him better control of his product, saves tool grinds, and many other benefits. The quality control engineer should impress all these points upon the operator.

There is another real result from this method. It is a tangible proof that management is sincerely behind the quality control program. The operator is quick to realize when management is only "talking" quality control and when they really mean business. If he can see by action that management is solidly behind the work he will tend to be more impressed with the program.

CORRECTING EQUIPMENT

Following close on the heels of the last mentioned technique is one which will really interest operators in the program and will tend to keep them interested. This method is the repair of machines where indicated, and buying new equipment where the old is not adequate to produce parts to specifications, and also buying new tools where needed. Each machine operator, worthy of the name, develops a great interest in his particular machine. He learns its peculiarities. He knows its capabilities. He generally knows what should be done in order to repair the machine so as to reduce variation He knows what type of tools he should have to do certain jobs. It has been my experience that these matters are quite often brought to the attention of the foreman who treats them merely as an alibi and promptly dismisses them. It is difficult to convince an operator who has had this experience that management is honestly interested in improving quality.

When the control chart reveals a machine to have excessive variation, and the investigation reveals the need of corrective action such as repair of machine, new tooling, etc., the operator watches with interest. If you make the necessary repairs or purchase new tooling, you will have convinced the operator that management is squarely behind your program. He will be convinced that the quality control program can get things done and you will have aroused his desire to be a part of such a program.

If management ignores the requests to correct equipment when it is shown to be necessary, it becomes very difficult to sustain interest on the part of the operator.

SUPERVISOR TO SHOW INTEREST

It is generally agreed that most operators are interested in that in which their supervisors are really interested. So we might say that one way of interesting the operator is to first interest his supervisor. Not all supervisors are interested; in fact, they are often the real stumbling block.

The supervisor can harm the program by ridiculing it behind the back of the quality control engineer. The operator quickly notices this and is not really interested in it thereafter.

The passive interest of the supervisor is not enough. He must show an active interest in the program. For example, if there are control charts on a machine, and days go by without the supervisor looking at them, it is hard to convince an operator that his boss is really interested. Therefore, the operator will quickly lose interest. Conversely, if the supervisor makes it a point to look at each chart and discuss it with the operator, questioning this point and that trend, the operator becomes convinced of his boss' interest and he too will become interested. One plant has solved this problem by requiring that the Supervisor actually select one sample per day from each machine in his area, calculate and plot values on chart and initial this point. Thus the employe's interest is being sustained because of the supervisor's active interest.

However, since this paper is directed to interesting the operator, we will leave the supervisor to someone else. We will assume that the proper parties have obtained his interest. Since the supervisory group is unusually small, several meetings will ordinarily suffice to cover the plant as far as supervisors are concerned.

PUBLICITY PROGRAM

Perhaps one of the most widely used methods to arouse and maintain their interest is some form of publicity program to inform entire plant personnel of quality control programs. These publicity programs take many forms and may include one or more of the following ideas.

House Organ

Many companies have either a paper or magazine which is periodically distributed to all employees. This medium is an excellent channel to place before the entire personnel articles designed to gain interest for quality control. An article concerning a simple explanation of what quality control is, how it works, and what its benefits are as pertaining to the specific company involved, is usually written to appear about the time the program starts. In this article, the personalities involved in the program are introduced, pictures are shown of operators concerned, etc. All this is designed not only to introduce the program, but also to gain the individual operator's interest by publicly identifying him with the program.

To maintain sustained interest, from time to time case histories are published in these same periodicals to show the results of quality control. A part of these articles should always be devoted to building up the operator's part in the achievement and, wherever possible using a picture. Most folks like to see themselves in print.

Posters

Attractive posters, strategically located throughout the plant are a means of awakening and sustaining interest. The posters should be located where

they can be easily seen. They should be changed often so that the employees do not become accustomed to seeing the same poster for long periods of time. They should be on a special bulletin board, if possible, so that they are not lost in the usual disarray of old bulletins, etc., that seem to be a part of most bulletin boards.

The posters should be well drawn and should be colorful. If you are fortunate to have an art staff, it may be possible to have posters made whose message is directed to specific problems in specific locations. Failing this, the poster services of certain well known management services do a very excellent job.

Scrap Displays

Another very effective publicity method to use in interesting operators is that of displays of parts scrapped by their operation. Several companies have built display counters in prominent locations in each department. On these counters, the accumulated scrap parts for a period of time are placed. The dollar value of these parts is shown alongside the display. This idea can be built into a very elaborate affair, depending upon the results obtainable from it. It has proven to be a most effective means for awakening operator's interest and as a means for reducing scrap. I believe that few operators actually realize the dollar value of the parts which may be scrapped because of their operation is below standard. Then this is visibly and forcibly brought to their attention by a display of this nature, the results almost always have been good.

Another variation is a large chart which will show the dollar value of scrap produced by the department each day. This chart should be very large so that the movement of the points can be easily read from a distance This chart should be mounted in a conspicious place. In one company of my knowledge, such a chart is mounted over the time clock alley. It has been very effective in reducing the scrap in that particular plant.

CONTESTS

There have been many companies which have instituted various types of contests in connection with quality control programs. Some require creating a slogan, some choosing a quality control queen, as well as various other ideas. The purpose, of course, is to arouse employee interest. The fact that so many companies have used this method must mean that it achieves results. It is necessary, of course, to have worthwhile prizes, and to provide adequate publicity to sustain interest in the contest over the required length of time.

One contest which is very much to the point, is one in which the departments are judged by the improvement in their quality noted over a period of time.

CONCLUSION

The degree to which the operator is interested in the quality control program will govern to a large extent the success of the program. This paper

has suggested some of the methods which can be used for obtaining this interest. There are undoubtedly many other methods which can be tried with equal success. Every quality control engineer will have his own approach to the problem of interesting the operator.

The question of operator interest is especially important to the quality control engineer who is just installing a program, especially when he has not had experience in dealing with this problem. A paper, or series of papers which would set forth as many ideas as possible so that they can all be weighed would be of great service to all quality control engineers. It is my earnest wish that my colleagues will aid all of us by presenting more thorough discussions of this subject than has been done in this paper.

REFERENCE

(1) Industrial Quality Control Vol. VI - No. 3 - November, 1949
"Operator Interest and Cooperation in Statistical Quality Control"
by A. H Becker

INDUSTRIAL TRAINING OF QUALITY ENGINEERS AND SUPERVISORS

Edward A. Reynolds
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A supervisor or engineer in industry normally improves in ability and value through one or more of four possible types of training. These are:

> Experience Training—primarily self-acquired on the job by contact with the day-to-day problems.
>
> Guidance Training—from personal contact with his superiors (sometimes with subordinates or equals) as they advise him on methods and actions.
>
> Independent Study—classes, technical meetings, study of books, etc., undertaken on his own initiative, without direct company sponsorship, and primarily in the direction of his personal interests and ambitions.
>
> Company Classes—training through classes or conferences conducted, or sponsored, by the company and in the direction of the company's interests.

More and more, companies are putting an increased emphasis on the last type of training—not because such classes are a satisfactory substitute for experience, guidance, or initiative; but because they are a necessary supplement when there is insufficient time or insufficient employee ability to depend solely upon the other three.

This is particularly true in many quality control groups, where new techniques and the handling of new functions must be learned by incompletely trained employees, or by employees trained through experience in older ideas and methods.

The writer recently secured information from inspection and quality heads in 56 companies regarding their training of inspection and quality supervisors and engineers. Of these, 48 either conducted company classes or paid for outside extension courses for at least some of their quality personnel, and 26 did both. However, over one-third of these men expressed dissatisfaction with their training programs and believed additional or improved training desirable.

It is the purpose of this paper to discuss some of the general planning and methods for class-type training of inspection and quality control supervisors and technicians in the hopes that this may be of help to the many companies requiring better training for this group.

Need for Training

The need for training is basically a function of the quality group's ability to handle its quality responsibilities. It can be measured by the complexity of the quality problems, the education, experience, and initiative of the quality personnel; and by the current rate of improvement in both the quality personnel and, solution of quality problems.

To those companies who are in doubt as to whether or not they require improved training, the writer suggests the following simple test:

1. Have you been able to satisfactorily fill most of your top and middle-level inspection and quality openings by upgrading from within during the past few years?

2. Are your inspection and quality supervisors and engineers becoming of increasing value to the company and advancing steadily in both responsibility and rate of pay?

3. Are many of this group doing independent outside study of newer quality control methods through extension courses, attendance at ASQC meetings, reading of technical books, etc.?

4. Have continuing and important improvements been made in your methods of machine control, gaging and testing; in your analysis and use of inspection and test data; your selection and supervision of inspectors; and in your general level of employee "quality consciousness" during recent years?

5. Have your quality problems reduced in seriousness and has your ratio of quality costs (including inspection labor, scrap, rework, etc.) lowered over the past year?

If your answers to several of the above are "No", you would do well to carefully consider the reasons and it is the writer's belief that you will find insufficient training of your key quality personnel to be an important factor.

Preliminary Approach to Training

Before embarking on the details of what, when, where, and by whom training should be conducted, it is suggested companies planning extension of their quality control training give consideration to the following:

1. Make sure the personnel to be trained is suitable. The training objective, the training method, and the caliber of the personnel available for training are all tied together. One cannot be considered logically without consideration of the other two. Training of any type is like manufacturing itself, in that it requires first a design of what we wish to turn out; secondly, raw material from which the product is to be made; and then thirdly, a process for transforming the raw material into the finished product. No worthwhile training program can be established without full consideration of what is actually desired and what is available to make it from. The greater the spread between these two points, the more extensive is the training required.

   If the available personnel are not capable of being transformed into what you desire, then you must either lower your sights for the end results, or secure better quality material at the start. This does not mean that you must have top grade engineers before you can have a successful training program, but if you really require Quality Control Engineers trained in statistics, in test and inspection methods, in gage selection or design, in technical investigations, in report writing, and in the selection and supervision of inspectors; then you require a level of mental ability and training comparable

to those for Design Engineers, C.P.A.'s, or Research Chemists. Do not attempt to make full-fledged Quality Engineers from personnel you would unhestitatingly reject for other equally complex positions.

2. Consider possible changes in personnel. In planning your training program, take into consideration possible changes in your products and organization, and especially consider possible turnover in your personnel. Some companies have embarked on long term programs for one or two picked employees only to have these men leave the company or be promoted to other jobs before putting their training into use. Such changes can never be completely foreseen, but their seriousness can be reduced by advanced consideration, inclusion of understudies in at least a portion of the program, and coordination of definite upgrading with your training program.

3. Encourage cooperation from the men to be trained. Discuss your training needs and preliminary plans with those men who are to be trained in advance of establishing a definite program. To do so will not only give you the benefit of their ideas, but will also encourage their cooperation from the start. It is entirely possible to initiate a training program by either direct or indirect compulsion upon the trainees. However, if after a few sessions the men being trained are not sufficiently interested to actively desire continuation of the training program, then they may as well be dropped from further training. Without their wholehearted interest and cooperation, it will not succeed and it is extremely helpful if this cooperation can be secured at the beginning of the program.

   Plan, too, the details of your training program to encourage the continued cooperation and support of those being trained. This includes making sure that the classes are as interesting as possible through careful selection of the instructor, use of visual aids, models, etc., and it also includes consideration of such details as time of classes, comfortable facilities for classes, payment for meals if classes are outside of regular working hours, supplying of interesting texts, and class visits by top executives.

   Plan also so that if some of your trainees drop from the program, either by their own choice or because it has become apparent that they are unable to absorb further training, that this can be done without their embarrasment or discouragement.

4. Plan the training program completely but allow for possibility of changes. In planning your training program, plan it completely on a long range basis but provide for frequent reviews and changes in the tempo or subject matter whenever this appears desirable.

5. Plan cooperatively with your Training or Personnel Department. In those companies with active Training Departments, any training program will, of course, be coordinated with their work and much, if not all of the planning will become their responsibility. Even if your company has no such department, or if they are unable to handle the quality training program, every effort should be made to have the Personnel or Industrial Relations section an active partner in the program. In addition, if your company has generally unfilled training needs, the introduction of a quality training program may well be the occasion to consider an overall training responsibility to coordinate administrative and planning details. However, in any event, the Quality Manager or his superior must also assume his share of the responsibility for the technical planning.

6. Consider possible inclusion of other departments in the training. Frequently, Industrial Engineering, Design, Research, and Production personnel can profit from some of the same training planned for Inspection and Quality Control. Inclusion of these groups may not only benefit the other departments but will also improve inter-department cooperation and understanding.

Subjects to be Taught

The actual subjects in which training is required will, of course, vary with each company; and may include such diversified items as statistics, precision measurements, bacteriology, metallurgy, personnel supervision, inspection work simplification, job evaluation, etc. Likewise, the degree of training required in each subject will vary with each company, and precision measurements to one may require training in use of a micrometer and to another require instruction in surface plate gear checking. The training program must be established by someone who knows both the company methods and problems and also knows the latest techniques in those fields. Where this latter knowledge is not available in the company it will be necessary for the executive responsible for the Quality group to secure outside advice. In such instances, the local ASQC should be able to provide assistance.

In most cases, it will prove helpful to list the requirements for each Quality job and record the present degree of competence of the employees.

Comparison of job descriptions, as presently performed, and as desired, will also highlight training needs.

Types of Training Classes

Once you have decided that a training program in specific subjects is desirable, the final considerations will be where, when, how, and by whom such training shall be conducted. The decision as to whether classes shall be on company time or employees' own time is one in which company policy and, in some cases, labor laws or contracts, must be considered; as well as the availability of the men during working hours. The various types of classes as discussed below.

In-Company Classes

In-company classes have several important advantages over most extension courses conducted outside. They permit the group to work with actual company data on company problems and permit guidance of the training in the specific directions most valuable to the company. They also permit better evaluation both of the men being trained and of the effectiveness of the classes. Where necessary, changes in the speed or direction of training can be made much more easily than in a program of outside courses.

The major drawback to in-company classes is the securing of a qualified instructor. If one is not available within the company, it is sometimes possible to secure outside experts from local colleges, other industries, or consulting firms but here much of the advantage of specific company knowledge and direction is lost. One other method, which the writer has used with some success, is the practice of having various members of the training class themselves teach specific portions.

This requires that they study this phase in advance and therefore frequently learn it themselves better than they otherwise would. It also gives them valuable experience in teaching and in preparing technical notes and reports. However, it should be kept in mind that this method can only be used if there is some overall guidance and if the selected men have initiative plus a preliminary basic knowledge of the subject.

In-company classes have an additional disadvantage in that the training is sometimes so specific on company problems that the trainees fail to grasp a broad or fundamental understanding of the ideas or methods being taught.

It is the writer's recommendation that in-company classes be used only under the following conditions:

a. The subject to be taught is not a general one or else specific advanced training is required. (Good general courses in measurement inspection, statistics, etc., may be too readily available in most areas to warrant special in-plant classes unless the group is very large and qualified teachers are easily available within the company.)

b. There are more than three or four persons to be trained in the same subject.

c. An instructor is available either within the company or from the outside, who both knows the subject expertly and has the ability to convey his knowledge in an interesting manner.

d. Someone in the company (or the outside instructor) can take time to carefully plan the classes, prepare interesting examples, models, etc.

Outside Extension Courses

The outside extension courses conducted by a technical school or a technical association normally have better teaching equipment than available to the company classes. The quality of the teaching staff may, however, be inferior with respect to practical experience and too many extension courses tend too highly toward the theoretical. There are, however, many notable exceptions of excellent extension courses taught by experts in the industrial applications as well as in teaching methods. (This is particularly true of many of the part-time and the full-time short training courses available in the statistical aspects of quality control.)

Generally, the writer suggests that outside extension classes be used (where available) in preference to company classes, provided the course content and the teacher's ability have been carefully checked and found to be suited for the training required. Under these conditions, the quality of training will usually be better and appreciable time saved for the company staff.

Unfortunately, extension courses are presently not generally available in many phases of inspection and quality control for which industrial training is desired. The comments in a recent sampling of Inspection and Quality Managers indicates that most believe such subjects as Production Trouble Shooting, Personnel Management, Inspection Work Simplification, Gage Design, and Automatic Controls have been too largely

neglected by colleges and technical associations in their extension training. On the other hand, the statistical techniques of quality control have perhaps been overemphasized. (In fairness to the universities and ASQC, it should however be kept in mind that the techniques of such subjects as Gage Design and Production Trouble Shooting are quite specialized by type of industry; whereas, the same general statistical techniques can be taught with less regard for product and process differences.)

It is hoped that the difficulties of extension training in additional quality control subjects can be overcome and it is suggested the the ASQC and its interested members give the problem their attention. In areas where there are several generally similar industries, grouping of their requirements could make possible such courses conducted either by technical colleges or by the ASQC chapter itself.

Study of Technical Books

There are presently available excellent training texts in several phases of inspection and quality control and, if other means of training are unavailable, it should be entirely practical to train primarily by a program of home study, under the following conditions:

a. The trainees must have a real interest in learning and initiative to work alone at home.

b. The text must be suited to the prior education of the trainees.

c. Definite sections to read and problems to be solved should be assigned weekly and problem sheets reviewed by the "instructor" (who, of course, must have at least studied and understood the text).

d. Short group conferences of the instructor and trainees should be scheduled weekly, at a regular time, to discuss current studies. (Occasional outside speakers or the showing of training films on statistics, gaging practices, etc., can also be used to advantage at these conferences.)

Summary

In summary, the writer suggests the following approach to training:

1. Determine your training needs; including the subjects and extent of training required in each.

2. Make sure your personnel is suitable to profit from the training.

3. Plan carefully in advance to secure the cooperation of the trainees, as well as of other groups in the company.

4. Use outside extension courses, where available, but only after making sure they are suitable.

5. Use company classes where necessary and make every effort to secure competent instruction.

6. Where limitations of qualified instructors, organization or company policy prevent the training believed desirable, utilize whatever methods are available, as long as they permit some progress in the

desired direction. Training can be done by encouragement of home study or by group discussions, where these are the only immediate approaches.

7. Call upon the ASQC for assistance and attempt to secure its activity in all phases of quality control—not just in the statistical techniques.

8. Realize training classes are only a supplement to proper selection, guidance and upgrading of employees. Use them as an aid, not a replacement, for good personnel policies.

PRESSED METAL - IN PROCESS CONTROL TECHINQUES

Glenn U. Hinds
Buick Motor Division, General Motors Corporation

It shall be the purpose of this presentation to provide a working S.Q.C. tool, based on results of case studies and containing sufficient detailed description to enable the establishment of similar procedures in other plants.

It might be well at this point to indicate the diversified operations upon which Statistical Quality Control techniques have been used at the Buick Motor Division and also to show the organizational structure of the S. Q. C. program and its relationship to the Inspection Department.

Figure 1 is a tabulation of the different plants in which S. Q. C. techniques have been applied at Buick. It must be recognized that the S. Q. C. potential of each of these plants has not been "exploited" to the same degree. This is true because not all operations are "naturals" for S. Q. C. techniques.

TABULATION OF PLANTS

FOUNDRY

FORGE

MOTOR

PRESSED METAL

AXLE

SERVICE PARTS

SYNCHROMESH TRANSMISSION

DYNAFLOW TRANSMISSION

FINAL ASSEMBLY

SEVERAL DEFENSE PLANTS

Figure 1

Figure 2 is an organization chart of the Buick Motor Division Inspection Department.

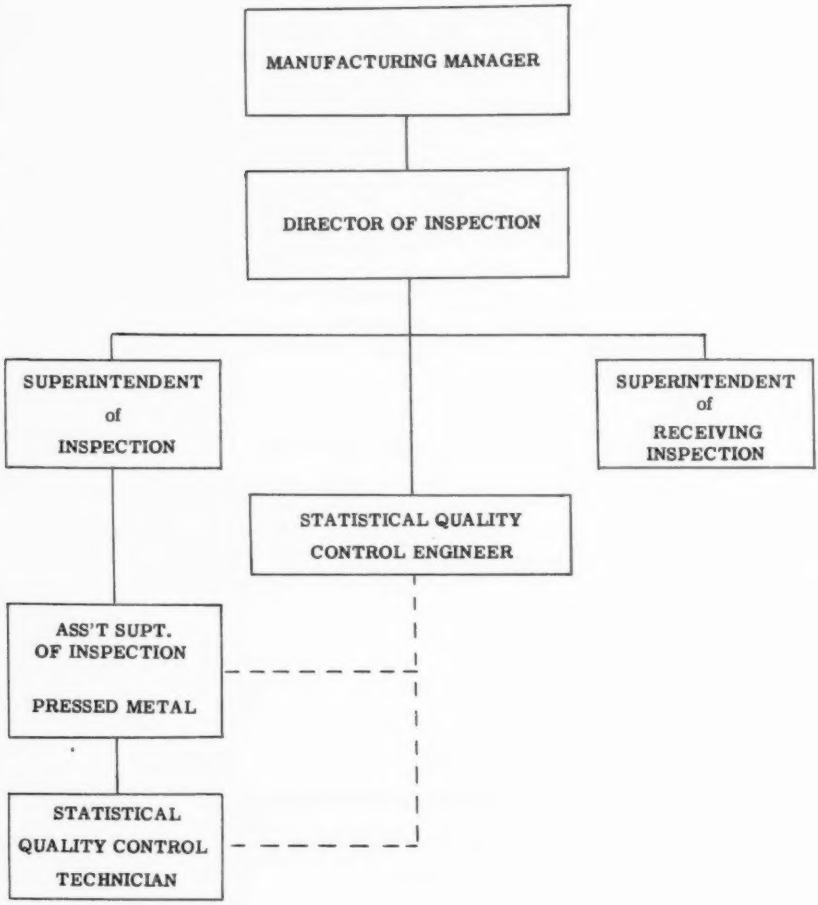


Figure 2

I feel it necessary to show the relationship between the S. Q. C. and inspection organizations. You will note, in Figure 2, that S. Q. C. is a function of the inspection activity. In most of the plants, the services of a S. Q. C. technician are available. The technician, however reports directly to the Assistant Superintendent of Inspection of that plant; The S. Q. C. Engineer acts only in an advisory capacity to the technician.

As noted by the title of this paper, the topic selected is "Pressed Metal In-Process Control Techniques". The Buick pressed metal plant is divided into two main sections; the "large press room" and the "small press room". The large press room fabricates hoods, fenders, etc., while the small press room fabricates the thousands of small stampings necessary for automotive production. The technique which is presented in this paper is applicable to small press operations. The system of inspection used prior to the installation of the S. Q. C. technique is shown in Figure 3.

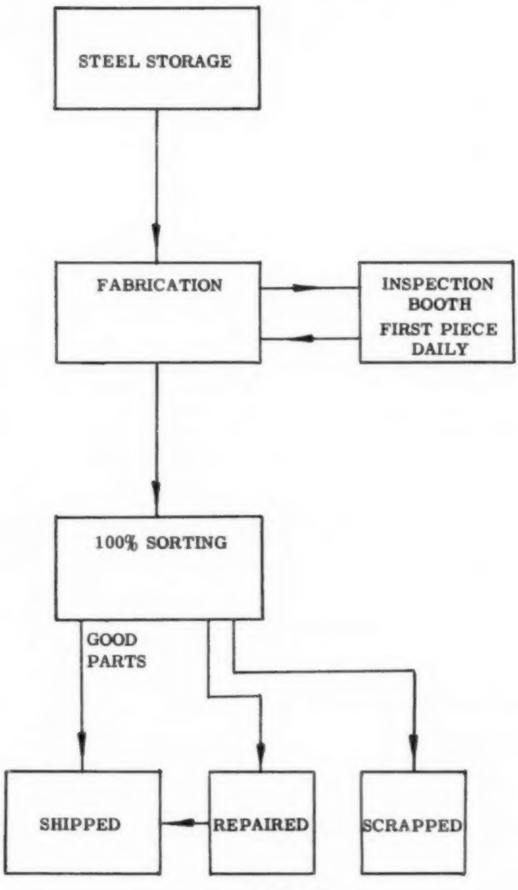


Figure 3

Figure 3 is a Material flow chart through the small press room. The steel was released to the production department at which time the die was set in the press. The press operator took his first good pieces to a central inspection area which we call the inspection booth. The inspector in the booth checked the part, over gages and/or by visual comparison with a sample of that part. If the part was satisfactory, the press operator's production card was signed, authorizing him to run his required production. No further process inspection was performed on the part until the next shift or at such time as the die was pulled from the press. After the parts had been fabricated they were sent to a shipping inspection area and, either 100% inspected, or subjected to a questionable sampling procedure. The parts were then shipped. This system had the advantage of being simple to operate with a minimum of paper work. This system did, however, provide the possibility of running 8 hours scrap before being caught. In effect, the entire inspection function was little more than a sorting activity.

Recognizing this procedure as being inadequate, the possibility of a revamped system was studied. Any system to be put into effect must have four prime requisites:

1. The system must be simple

2. The system must involve process inspection

3. The manpower requirements must be kept to a minimum

4. The system must provide a desired calculated risk

The first attempt made in installing a system which would meet the above requisites was a system involving the use of a conventional sampling procedure; the samples to be drawn at regular intervals from the production. This system was put into effect and it met two of the above requisites; it provided a desired risk and it was process inspection. It did not, however, keep manpower requirements to a minimum and the determining of the sample size for each regular interval was anything but simple. When a part had been authorized to run, the S. Q. C. inspector had to calculate the sample size for each check by working backwards. It was necessary to estimate the sample lot size by estimating the number of hours the production lot would run and dividing the total production required by the estimated hours; the resulting quotient being the sample lot size. Following this step, the proper sample size and acceptance number was selected from a set of sampling tables. A simple example will suffice. (See Figure 4).

EXAMPLE

PRODUCTION REQUIRED	**40,000**
ESTIMATED TIME	**20 HOURS**

$$\textbf{SAMPLE LOT SIZE} = \frac{40{,}000}{20} = \textbf{2,000 PARTS/HOUR}$$

Figure 4

The normal desired time interval was one hour. Even if our S. Q. C. inspectors were capable of continuously making this type of calculations without error, it would require an inspection force twice as large as the existing one. Another factor complicated the use of this system. After a sample lot size had been determined, the validity of the sample's results was distorted if a portion of the parts were taken from the gondola; a frequent occurrence in Buick's press room. Another problem is the moving of filled gondolas from the press between the hourly checks. There is no question in my mind as to what management's reaction to this system would have been.

Recognizing that no existing sampling tables could provide all the factors desired and yet be flexible, it was necessary to design a procedure into which a suitable sampling procedure could be incorporated. It was felt that the procedure should incorporate some of the characteristics of multiple and continuous sampling. With this in mind, the straight line equation $Y = MX + b$ was adopted and modified to:

$$C = AQL\,(n) + d$$

WHERE:

C = Acceptance number

AQL = Acceptable Quality Level

n = Number inspected

d = Defectives (corresponding to "Y" intercept)

Using this equation as a basis, the form shown in Figure 5 was designed. In an attempt to make the procedure as simple as possible, a basic sample size of 50 was established with an AQL of .05 or 5%. The value of d was established at 3 after drawing operating characteristic curves for several values of d. You will note in Figure 5 that all information concerning the identity of a specific job was carried at the top of the sheet.

TALLY SHEET

PART NO. ______________ OPERATION ______________ DEPT. NO. ________

PART NAME ________________________________ SHIFT __________

REQUIRED PROD. ______________ PROD/HOUR __________

TOOL NO. ______________ PRESS NO. ______________

ACCEPTANCE NO. EQUATION $C = AQL\,(N) + 3$

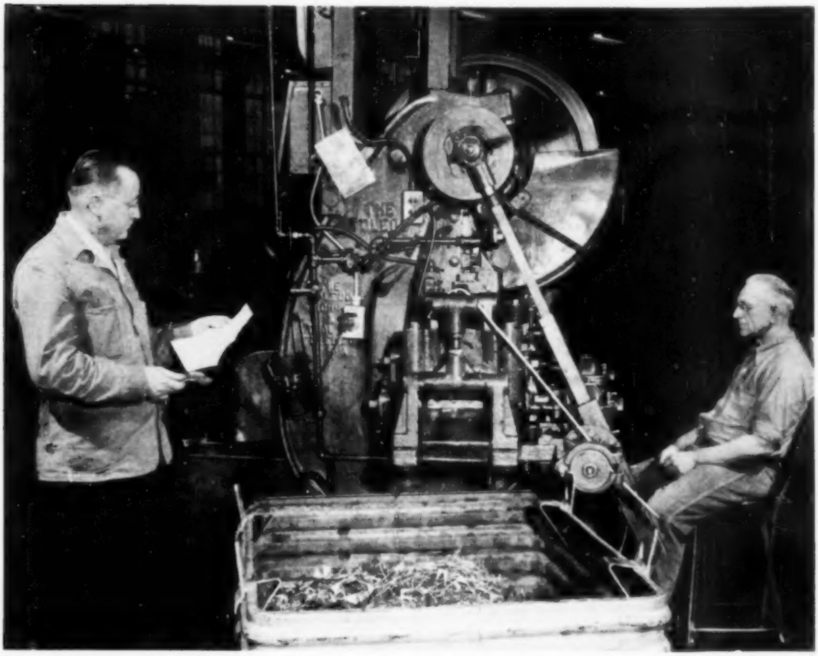
DATE	TIME	TALLY OUT / TALLY IN / LOT SIZE	SUB SAMPLE SIZE	CUMULATIVE SAMPLE SIZE	DEFECTIVES		ACC.	REJ.	REMARKS
					NO.	TOT.			
TOTALS									

TIME DIE PULLED ______________ REASON ______________

INSPECTOR

Figure 5

This information was obtained from the production card which the press operator brought to the inspection booth when the operation was authorized to run. The information at the top of the form was filled out by the booth inspector and given to the S. Q. C. inspector. The form was placed in a cellophane envelope on the press and remained there until the end of the run.



See Figure 6. The left hand column provides a space for the date and time. In the next column, "Tally Out" and "Tally In" values were taken from the press counter. The difference between these two is the production which has run in that interval of time. This column was used only as a survey of sample lot sizes and had no bearing on the selection of the sample size. The third column contains the information as to the basic sample size which was standardized at 50. A cumulative sample size value was recorded in the next column. This was used so that the total number inspected was always available. This is always the summation of column 3. The actual number of defectives found in the samples was placed in the 5th column. The "Total" section of this column is again the summation of the

"Number" column. The decision to accept or reject a given lot was based on both the basic sample of 50 drawn each hour, and also on the cumulative sample. The S. Q. C. inspector was required to substitute the value of n in the basic equation to determine the cumulative acceptances number. Perhaps a simple example will aid in explaining the system. See Figure 7.

TALLY SHEET

PART NO. 1342721 OPERATION 20 DEPT. NO. 30

PART NAME Washer Cup SHIFT 1st

REQUIRED PRODUCTION 132,400 PROD/HOUR 3200

TOOL NO. T-943-A1 PRESS NO. 343

ACCEPTANCE NO. EQUATION C = AQL (N) + 3

DATE	TIME	TALLY OUT / TALLY IN / LOT SIZE	SUB SAMPLE SIZE	CUMULATIVE SAMPLE SIZE	DEFECTIVES NO.	DEFECTIVES TOT.	ACC.	REJ.	REMARKS
9-24	8:45	68200 66400 1800	50	50	0	0	✓		
	10:00	71300 68200 2900	50	100	0	0	✓		
	11:15	73650 71300 2350	50	150	4	4	✓		Bad Stock
	2:15	77000 73650 3350	50	200	3	7	✓		
	4:30	80032 77000 3032	50	250	25	32		✓	Informed production
TOTALS									

TIME DIE PULLED 4:45 REASON

Broken Punch

RJK

INSPECTOR

Figure 7

This system seemed to be functioning extremely well. In our way of thinking every possible refinement had been made. A few of the General Motors Divisions had heard about this system and sent representatives to the Buick Press Room to view the procedure. On one of these occasions, after explaining the system, one of the visitors suggested another method by which the procedures could be simplified.

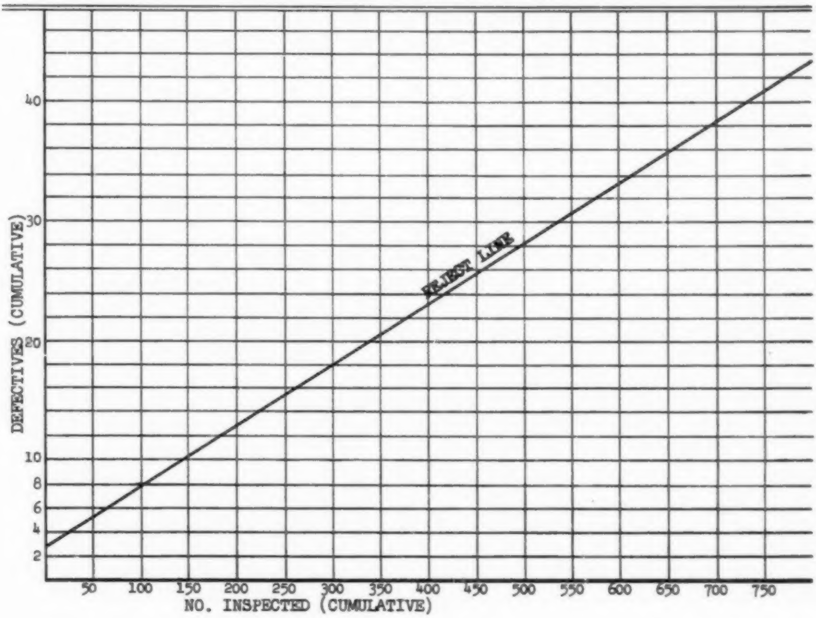
TALLY CHART

PART NO.________ OPERATION____________ PRESS NO.__________ DEPT. NO.______________

PART NAME______________________________ DATE STARTED______________ SHIFT________

TOOL NO.________________

PRODUCTION LOT SIZE____________________ PRODUCTION PER HOUR____________________



Instructions (1) Anytime the cumulative defectives exceed the Reject Line at the corresponding cumulative number inspected, (2) or anytime there are more than 5 defective parts occurring in one sample of 50; place a red tag on lot and inform the foreman of that department.

Nature of Defectives and Remarks:____

Figure 8

Inspector

See Figure 8. He suggested placing the Reject Line, which is the basic equation plotted out, on a graph. The information regarding the identity of the operation and part is still carried at the top of the form. The body of the form can be recognized as being similar to that used in true multiple sampling. The vertical axis represents the cumulative defectives while the horizontal axis represents the cumulative parts inspected. As noted in the Instructions, whenever the cumulative number of defectives exceeds the Reject Line, the lot is rejected, or whenever the defectives in any one sample of 50 parts exceed 5, the lot is rejected. Again an example may aid in explaining. See Figure 9.

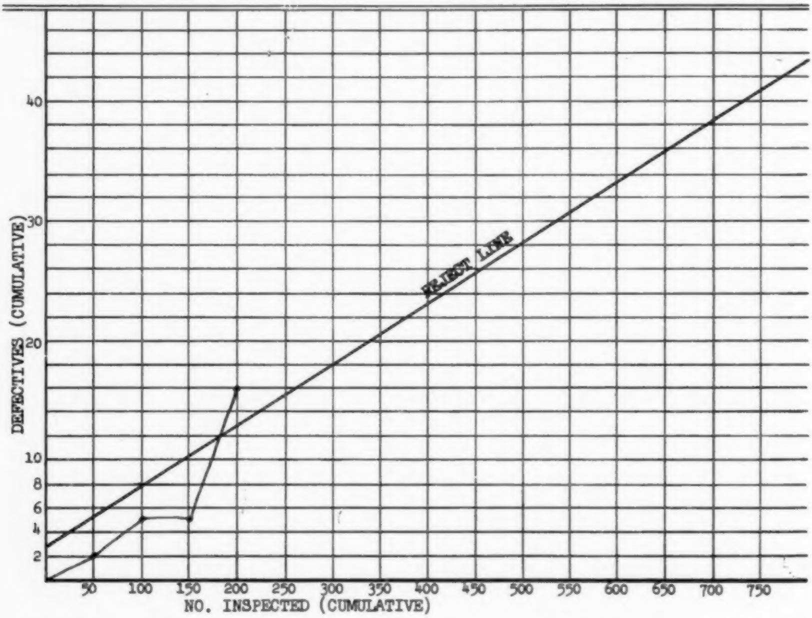
TALLY CHART

PART NO. 1337114 OPERATION 30 PRESS NO. 339 DEPT. NO. 30

PART NAME Grease Retain Cup DATE STARTED Nov. 2 SHIFT 2

Tool No. T-164-A5

PRODUCTION LOT SIZE 32,000 PRODUCTION PER HOUR 2000



Instructions (1) Anytime the cumulative defectives exceed the Reject Line at the corresponding cumulative number inspected, (2) or anytime there are more than 5 defective parts occurring in one sample of 50; place a red tag on lot and inform the foreman of that department.

Nature of Defectives and Remarks: Excessive burr, lot rejected and submitted to production

J. A. R.

Figure 9 Inspector

The question is frequently raised, "Did this system meet the four requisites established earlier"? In answering this question, we have only to analyze each of the requisites.

1. The System Must Be Simple

With the new system in effect the Material Flow Chart is shown in Figure 10. The steel is released to the Production Department at

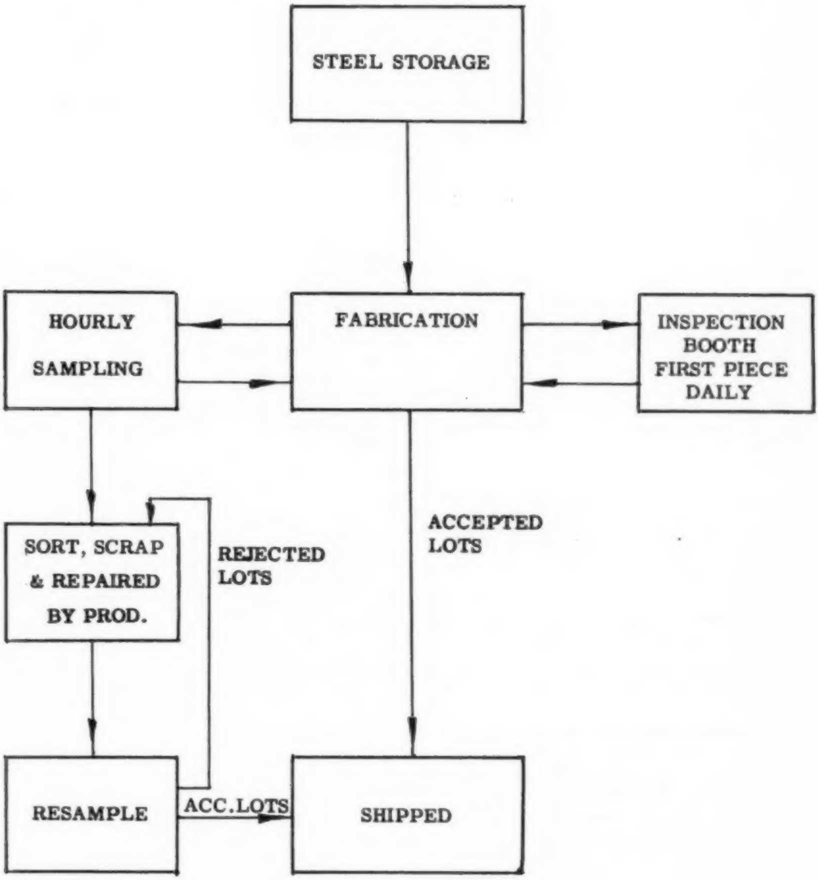


Figure 10

which time the die is set. The first good part is taken to the booth inspection area. If the lot is authorized to run, the press operator's production card is signed. The booth inspector gives the information to the S. Q. C. inspector who begins the system of sampling. At the time the first sample is drawn, an O. K. Tag is placed on the gondola; serving notice that the stock in it is good stock and has been accepted by inspection. This tag provides the material control personnel with an authorization to move. If the parts are needed in another plant, or if, for any reason, the gondola is pulled by the Material Control men, the presence of this tag is sufficient authorization. Generally an attempt is made to take a sample from the lot just before it leaves the department. If the lot is rejected, the O. K. tag is removed from the gondola, and a red "Hold" Tag is placed on the gondola. The foreman of the department is informed, and the job is stopped. The gondola is pulled from the press and moved into a Quality Control area. Production is then charged with the responsibility of sorting and repairing these parts. The lot is then resubmitted to the shipping inspection area for re-sampling and shipping.

2. <u>The System Must Involve Process Inspection</u>

The system very definitely involves process inspection. It brings the inspector, who previously sorted stock in the shipping area, to the processing area where they operate most effectively.

3. <u>The Manpower Requirements Must Be Kept To A Minimum</u>

Every system must pay for itself; either in cost of operating it or in improved quality. In the one department currently under this system, a total of five S. Q. C. inspectors are used. The one department in which this procedure is currently being used, has 39 presses; most of them automatic. This system uses three men on the first shift and two on the second shift. The inspectors now being used were transferred from the shipping inspection area. In evaluating the manpower requirements accurately, it should be added that the installation of this procedure in the other three departments of the small press area will require four additional inspectors. Two of the required four inspectors can be obtained from the shipping inspection area; the other two will have to be added. The transferring of inspectors from the shipping inspection area is justified by the fact that the inspection load in that area is reduced as the amount of process inspection increases. It should also be recognized that the shipping inspection activity cannot be eliminated because lots which have been rejected and re-submitted are resampled in the shipping inspection area.

An interesting phenomena took place with reference to scrap in this department. The system was started the middle of July. The average department scrap of the six months prior to this time was .49%. The average scrap for the five months following the installation of this system was .25%; based on an average of about 9,000,000 parts monthly. This is shown graphically in Figure 11.

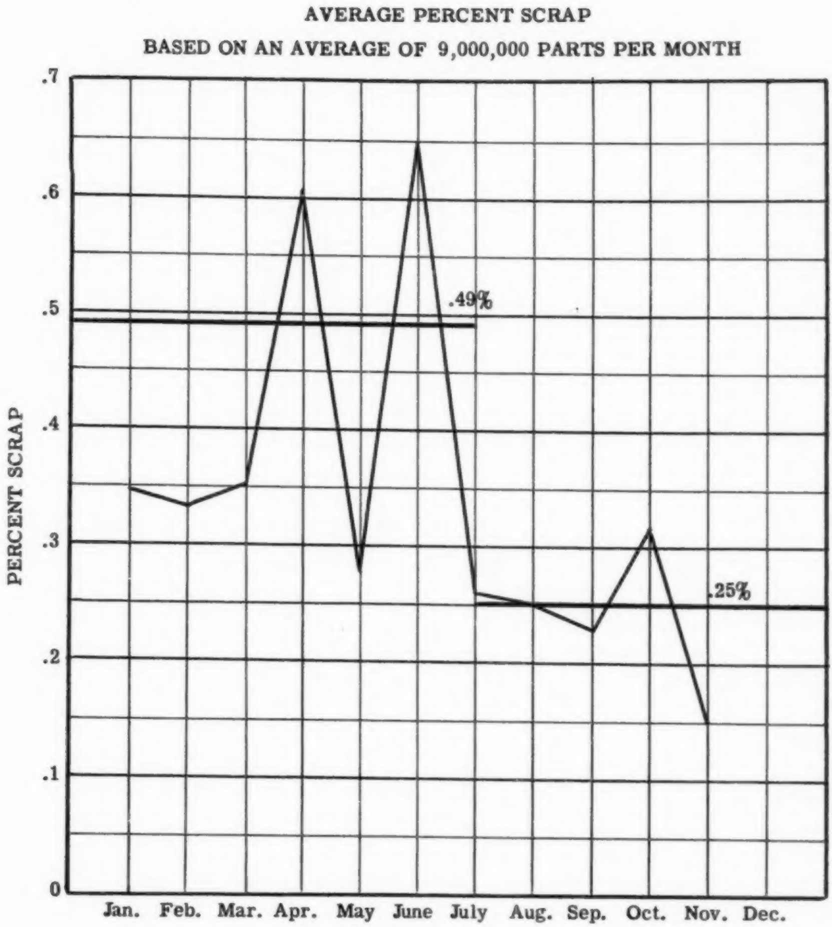


Figure 11

4. <u>The System Must Provide a Desired Calculated Risk</u>

It is sometimes difficult to determine what risk can be taken in a sampling procedure. The customer of the product naturally desires a percent defectiveness of zero, while the producer is desirous of making a quality part at as low a cost as possible. The amount of inspection performed to obtain the desired degree of quality affects that cost. Before the installation of this system, the risk being taken both by the producer and the consumer was not known because of the error in 100% inspection and the "hit or miss" sampling procedures used. To indicate the calculated risk taken on both the single sample basis and the cumulative sample basis as compared with that taken in using the MIL-STD-105A tables, the Figures 12 and 13 were made.

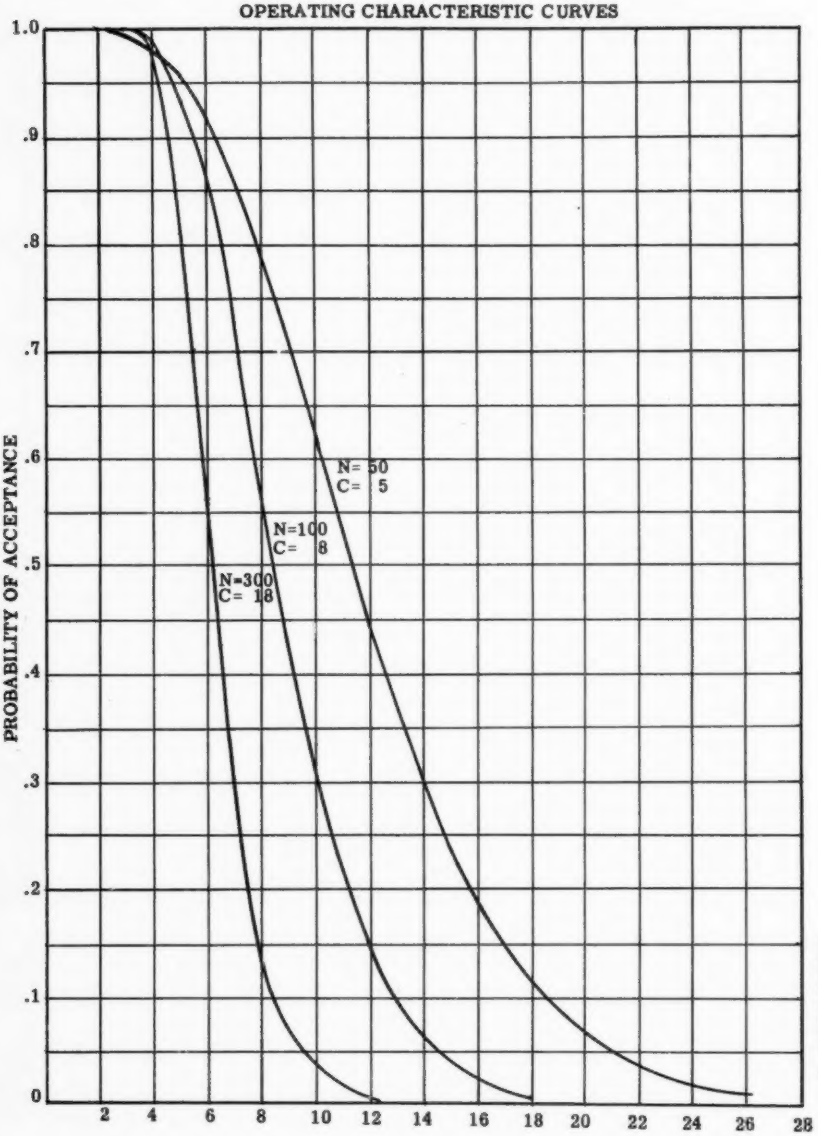

OPERATING CHARACTERISTIC CURVES
PROBABILITY OF ACCEPTANCE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
N= 50
C= 5
N=100
C= 8
N=300
C= 18
2
4
6
8
10
12
14
16
18
20
22
24
26
28
% DEFECTIVE

Figure
12

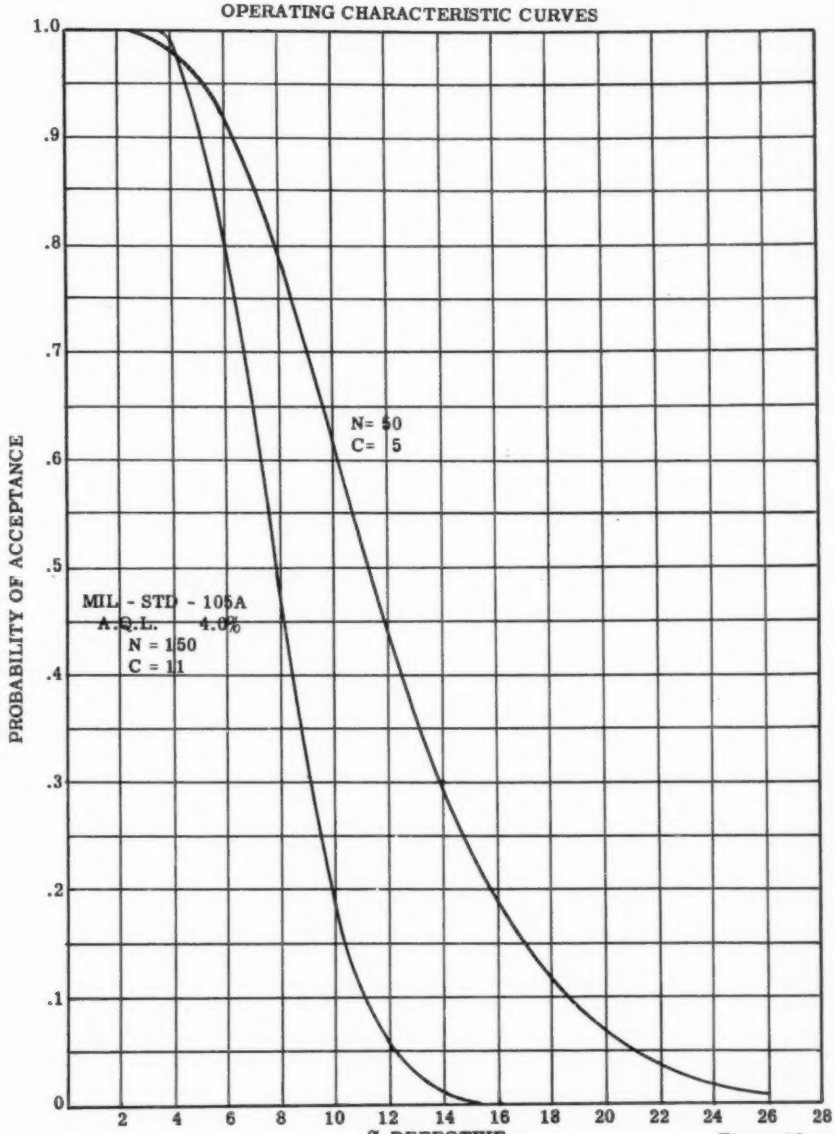


Figure 13

In Figure 12, three O. C. curves are shown for sample sizes 50, 100, and 300. In analyzing these curves, it will be noted that as the sample size increases, the probability of acceptance decreases. In Figure 13, the most lenient sampling plan used in this procedure is compared with a MIL-STD-105A plan with an A. Q. L. of 4%. This is assuming normal inspection with a lot size of approximately 2,000 parts.

The question has been asked many times in the discussions of this system as to why a control chart technique isn't used. There are two basic reasons for using a sampling procedure:

1 - There is no problem of storing charts and boards

2 - There is no calculating of control limits

The advantages of this system are:

1 - A more thorough inspection procedure

2 - Faster inspection procedure

3 - Indicates trouble faster

4 - Places the responsibility for quality on the production department where it should be

5 - There is a continuous decision on production lots currently running

6 - Disposition of rejected lots is a production function

This system has assisted in obtaining better quality with a reduction in overall costs: justifying the existence of a Statistical Quality Control function.

THE USE OF STATISTICS IN FOOD PROCESSING

Stephen Harrison
Research Laboratories
Kraft Foods Company

The progress of statistical thinking and statistical quality control in the food industry has not so far been striking. In seeking a reason for this, it is natural to ask if there are special characteristics inherent in food processing which make effective statistical applications difficult.

What are the special features of food processing? From our point of view, the most obvious characteristic is high variability.

1. Variability of Raw Materials

   The raw materials of the food industry are almost entirely of biological origin, so it is not surprising that they display the fundamental biological property of variation. Those who have worked for years with a particular food product will tell you that they still get surprises regarding the nature and behavior of their raw materials--the variety is apparently endless. Apposite is the saying so often heard in the Dairy Industry; "Every day's a new day in the Milk Business".

2. Variability of the Process

   Very small changes in the processing variables often cause very large changes in the final product, e.g., the drying of tapioca starch gel or the preparation of enrobing chocolate with just the right physical characteristics.

3. Variability of Evaluation Techniques

   Evaluation techniques in the food industry present something of a problem. Some types of estimation are relatively precise, e.g., the determination of refractometric solids. Many procedures, however, involving chemical analyses or complex empirical instrumentation are typically not very precise. This applies also to bacteriological procedures and biological assays. Quite often the techniques themselves are controversial; for example, the problem of deciding just how relevent are different techniques for measuring the physical properties of gel-formers like agars and gelatins. Perhaps most difficult of all is the evaluation of the organoleptic quality of the products.

   Not only do many of these techniques lack precision, they are also often time-consuming--obviously an important consideration from the point of view of on-the-spot quality control.

   The writer does not believe that these characteristics of food processing in any way exclude the application of statistical quality control. It seems likely, though, that methods worked out principally in the engineering industries will need a little modification and interpretation before they will "fit" the food industry.

The statistical approach to quality control in the food industry will now be considered under four headings; weight control, chemical composi-

tion, physical properties and organoleptic properties.

1. Weight Control

The weights of packages or units of a food product leaving the filling machine exhibit, of course, a certain degree of variation and a distribution which are characteristic of that particular machine and process.

It is customary in statistical quality control to distinguish between non-assignable and assignable causes of variation. The non-assignable are those irreducible random causes of variation inherent in the process and for which no adjustments can be made, short of modifying the design of the process. A process showing only these variations is said to be "in control". Assignable causes of a specific nature are those which introduce additional variation into the process over and above the background variation. The function of the quality control chart is to distinguish between these two kinds of causes of variation, that is to say, to tell us when an assignable cause has made its appearance so that we can either eliminate the cause or adjust the process in some way so as to neutralize its effect.

In food processing, assignable and non-assignable causes of variation grade into one another in a disconcerting fashion. Between the two extremes lies a broad penumbra of doubtful cases. For this reason, we have been led to redefine the notion of assignable cause for our own private purposes in a way which is of greater operational value. For us, an assignable cause is one which produces its effect long enough for it to be worth-while making a compensating adjustment to the filling machine. By "long enough" we mean that the period of operation of the cause is longer than the intersampling period, i.e., the time interval between successive check-weight samples.

This leads us at once to the question of how we ought to arrive at our estimate of the error variance upon which to base our control limits. This is usually done by taking a series (say, around 50) of small groups of samples, then determining the mean within-group variance. How should we space our sampling of the items within each group? Grant (1) offers us two alternatives; either sampling contiguous individuals or sampling randomly within an agreed time interval--say 15-20 minutes.

We have tried the experiment of spacing the sampling of individuals within groups over different periods of time, then plotting the within-group standard deviations against the interval over which the individuals were sampled in each set of groups. The smallest expected variance would be that based upon the squaring of successive differences where the individuals within each group are contiguous--that is, next to one another on the production line:-

$$s^2 = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n-1} (x_{ij} - x_{(i+1)j})^2}{2m(n-1)}$$

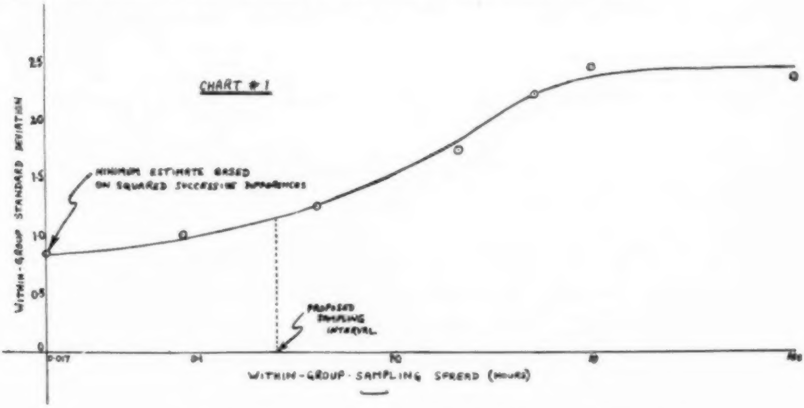
where n = number of individuals in each group
where m = number of groups.

The next variance calculated was based upon the same groups of contiguous individuals as employed for the above successive difference variance, only calculated in the normal way:-

$$s^2 = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n} (x_{ij} - \bar{x}_j)^2}{mn}$$

Five other mean within-group variances were calculated, the individuals within each group not being contiguous but spaced randomly over a certain time interval. This interval was, respectively, 0.4, 2.1, 5.0, 9.5 and 100 hours.

These sample variances were converted to unbiassed estimates of the corresponding population standard deviations and are shown plotted on Chart #1. A smooth curve has been fitted by eye.



As expected, the mean squared successive difference estimate was the smallest. The population variance corresponding to this estimate would not necessarily be the smallest of the various within groups population variances, since it could be inflated by a short-term negative correlation effect, but we have not so far observed this situation.

We decided that it would be desirable to take regular production samples for check-weighing every 15 minutes, since this would give the check-weigher time to supervise several lines. Reading off from Chart #1 for an interval of 15 minutes (0.25 hours) gives an s.d. value of 1.15. We based our estimate of our control limits for averages upon this. The difference between this standard deviation and the maximum (asymptotic) value shown on Chart #1 measures the maximum amount of weight variation which can be eliminated by this scheme of quality control. The extent to which this goal can be realized depends partly upon the extent to which this residual variation occurs as long-term trends. In the great majority of instances known to the writer, this tends to be the case.

We selected our intersampling period of 15 minutes in this in-

stance, since this was the best which could be done with the available staff. Actually, of course, we could have treated this more rigorously. The more frequently check-samples are taken, the smaller the s.d. upon which control limits are based. This means that the mean package weight can be allowed to approach the legal minimum a little more closely with consequent savings in materials. But more frequent sampling increases the cost of our quality control program. By graphical methods it would not be difficult to determine the optimum point giving the frequency of sampling which minimizes cost. In this case, it hardly seemed worth-while, since the slope of the line in Chart #1 in the region of our selected sampling period of 15 minutes is not at all steep so that large changes in inspection rate would produce only small changes in the spacing of the control limits. For example, doubling inspection rate in our case would reduce the s.d. upon which control limits are based by only 8-9%.

2. Control of Chemical Composition

A. Batch Processes

Where it is desired to control some element of chemical composition such as moisture content or salt content, perhaps the typical procedure is to check every batch before processing, standardizing where possible those found out of line. Both sampling and analysis error so that statistical procedures are needed to arrive at a rational rule to decide when the analytical results are sufficiently out of line to justify the conclusion that the batch requires adjustment. In order to do this, it is first necessary to determine the size of the sampling and analytical errors. Traditionally, the sampling error is disregarded entirely and the analytical error is assumed to be given by the mean difference between duplicates run through together by the analyst.

Actually, the adequate determination of analytical and sampling errors can best be made by a series of experimental sampling and analytical runs, designed so that the results are amenable to the analysis of variance. The reader is referred to standard textbooks (2) for an account of this method and to a recent article in "Industrial Quality Control" (3) for an application similar to the present one. We took two random samples from each of a number of batches and had a number of analysts located in different laboratories carry out four analyses on each sample. The analyses were carried out as two pairs of simultaneous duplicates, one pair carried out on one day and one on another. We partialled out the components of variance and got the following results:-

(1) Error variance (within simultaneous duplicates)	:	0.06%
(2) Between-periods-within-persons	:	0.20%
(3) Between-persons (and locations)	:	0.22%
(4) Between-samples-within-batches	:	0.08%
Total		0.56%

The total of the four components is a realistic estimate of the overall variance of the sampling and analytical procedure, and the corresponding standard deviation can be used as a basis for the calculation of quality control limits which must be ex-

ceeded before action is taken in standardizing a batch of material ready for processing. As can be seen, the overall error is far larger than the simultaneous duplicate variance alone, a fact which has been noted by Wernimont (4) and others. It has even been suggested that a simultaneous or contiguous duplicate be referred to as a "duplicity".

By reference to production records we obtained the analytical figures for 49 successive batches of the material and calculated their variance. All were analyzed by the same analyst so that the overall error should be items (1)+(2)+(4) above = 0.34%. The observed variance between batches was only 0.37%. This is not significantly greater than the overall analytical error of 0.34%, so that the real batch-to-batch variation is certainly negligible compared to the precision of the overall analytical procedure. In other words, the error of the controlling procedure is far greater than the batch-to-batch error it is supposed to be controlling. The upshot of this is that standardizing adjustments formerly being made on the results of analyses were increasing rather than decreasing the batch-to-batch variation.

It is evident that once realistic control limits for action have been established as described above, most of the normal batch-to-batch variations are going to pass undetected and uncorrected. However, such an analytical check does serve as a kind of coarse screen to sift out definite production mistakes; e.g., where an ingredient got omitted or a solution got routed into the wrong vat, etc. Also such a control procedure exerts a healthy psychological influence on production personnel.

It is particularly important to have a realistic estimate of overall analytical error when the chief object of the analysis is to ensure that composition meets minimum legal requirements. What one wants to know is not the average difference between two determinations both carried out at the same time and place, but rather the average difference between two determinations, one of which is done by you at one laboratory and the other by a government official at another.

Investigations into analytical error using the analysis of variance technique as described above may also give valuable insight into the method itself and also the analysts. The reader is referred to reference (3) at the end of this paper for an excellent example of this.

Owing to the necessity of getting results as quickly as possible, less precise short-cut analytical methods are often to be preferred to standard methods; also bringing the control laboratory within the plant (5) and streamlining communications so that plant operators take action with a minimum of delay greatly increases the effectiveness of quality control. Too often, in the food industry, so-called quality control consists of a department which finds in retrospect why something went wrong, or even worse, merely accumulates sheets and sheets of data which no one ever bothers to look at.

It is not always realized that routine analysts are subject

to inspection fatigue just as are Q.C. inspectors conducting, say, visual examinations of components for assembly in the engineering industry. This is particularly the case where samples with defective composition are very rare. The analyst becomes so accustomed to finding a certain percentage of a given ingredient in a sample that he may misread his instruments or make a computation error, so that, unconsciously, the result is made to agree with what is normally found. This situation is not easily remedied.

B. Continuous Processing

The trend in the food industry now seems to be toward continuous production techniques and away from batch processes. The tendency is for such processes to be smoother, more precise, and easier to control, especially where the batches of the corresponding batch process are small and numerous. Also, continuous production techniques may be amenable to control by servomechanisms. A start has been made in the food industry in the application of these elegant techniques to the control of concentration, pH, temperature and other factors (6). Such techniques imply, of course, a continuous automatic sampling of the product in process.

3. Physical Properties

When we come to consider the measurement of the physical properties of foods, we encounter some rather special difficulties. Many foods have important physical properties lying vaguely in the rheological field, which up until recently have had to be measured subjectively; for example, the grading of cheese for "body". Attempts have been to replace such subjective judgments by objective tests of various kinds, so that reliable estimates may be made by semiskilled technicians. Baron and Harper (7) have made extensive correlation studies on cheese, using a battery of six instruments (such as penetrometers, hardness testers, breakers, etc.) and a series of subjective ratings by experts for the qualities of "springiness", "firmness", "crumbliness" and overall quality. They subjected the matrix of intercorrelations obtained to a mathematical procedure known as "multiple factor analysis", developed by some mathematically minded psychologists (8). The object of this was to attempt to discover what basic variables lie behind all these tests and ratings and so gain insight into what is actually being measured. This in turn would suggest what further types of tests might be devised which would be an improvement on those already tried. Baron and Harper found that only four fundamental factors were required to account for all the observed intercorrelations. Multiple regression equations can, of course, be set up so that readings from different instruments can be entered into the equation which then gives the best possible estimate of the rating with respect to the quality in question without the use of experienced graders. It is perfectly possible for such a procedure to give a more reliable estimate of true grade than the judgment of a single skilled grader. Kramer (9) has published a series of interesting papers on the objective testing of the physical and organoleptic quality of vegetables.

Such studies could profitably be made of many food products

where physical properties are of cardinal importance, such as starch and agar gels, oil emulsions (e.g., salad dressing products) enrobing chocolate, etc.; relevent, rapid and precise objective methods of estimating physical characteristics would greatly assist quality control.

4. Organoleptic Properties

Organoleptic quality control of food products is carried out in two chief ways:-

A. By individual experts, as, for example, in the case of the wine and tea industries.

B. By taste-test panels.

The judgment of an expert may be more reliable than the average of the judgments of a group of panel members, but where there are no established experts, a taste-test panel procedure, properly conducted, is probably the next best thing. The one great advantage of taste-test panel data is that estimates of the standard error can be calculated in each case, which cannot be done for isolated judgments by experts. There is now an extensive literature dealing with the proper design of taste-test panel procedures and the statistical analysis of the data obtained.

With many food products, the chief cause of organoleptic variation is the progressive change in the quality of raw materials from the beginning to the end of the growing season, e.g., frozen vegetables, ketchup, orange juice, etc. In such cases, controlling the quality of the raw materials used may be the most effective single way of controlling the quality of the final product. Such control is typically done by graders, but here again there is scope for objective methods which may do the job as well or better (9).

The most obvious feature of organoleptic judgments is their low reliability, so that reliable estimates may require large numbers of individual judgments. But what is sauce for the goose is sauce for the gander; the fact is sometimes lost sight of, that the consuming public is probably not more, and may be a lot less discriminating in their organoleptic judgments. Furthermore, the conditions under which the product is normally consumed may be less critical for the detection of flavor nuances than those under which it is taste-tested by the producer. Perhaps ultimately the control limits of our control charts for organoleptic quality should be based upon measured estimates of the measured differences in quality which can just be detected by the average consumer.

In conclusion, there is no doubt that the food industry does have its special problems when it comes to the application of statistical methods and statistical quality control; but so has every other industry. Whether such problems are regarded as an obstacle or a challange will depend upon the morale of the industry.

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FUNDAMENTAL PRINCIPLES OF SEQUENTIAL ANALYSIS

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1. Brief History and Introduction

Work by Harold Dodge and Harry Romig, and Walter Bartky on double and multiple sampling respectively supplied background to the development of sequential analysis. Experimentation in successive stages was also suggested and used by Harold Hotelling and P. C. Mahalanobis. The problem of sequential analysis first arose in the Statistical Research Group of Columbia University in some comments of Captain G. L. Schuyler of the Bureau of Ordnance. Following this idea up, Milton Friedman and W. Allen Wallis conjectured that sequential procedures might be developed having as good control of errors of misclassifying lots, but which would require less average inspection. This was brought to the attention of the late Abraham Wald, who then developed the probability ratio sequential test, worked out the general theory of the test and its application to many important problems. Hence, sequential analysis is in large part a contribution of Abraham Wald. The foregoing is largely from reference (2) in the back of the article. Since 1945 there has been a host of articles deepening the theory and applying the sequential approach to many problems such as that of statistical estimation. See, for example, the references in the index to volumes 1 to 20 of the *Annals of Mathematical Statistics*

Fundamentally the aim of sequential analysis is to obtain decisions of requisite security on the basis of a smaller average number of tests or determinations than is possible even with the very best single sampling plans possible. (The saving is often as much as 50 °/o at critical levels of quality and considerably more at very good or poor quality.) The aim of this paper is to discuss briefly the fundamental principles of sequential analysis and how these work out in the various cases in practice. Further, we want to show how unified and comparatively simple the sequential plans are.

2. Definition of Sequential Analysis

In general, a sequential test is one in which, after each measurement or determination, we may either accept a hypothesis (or lot or process) reject the hypothesis, or request additional evidence. As such, the sample size is, in general, a variable; sometimes it is very small, while at other times it is quite large. Single and double sampling are special cases of sequential analysis, in which neither acceptance nor rejection is possible until n (or n_1) pieces are measured or tested. Thus the only decision on the earlier pieces is a request for more evidence. The sequential test terminates according to definite rules, that is, when sufficient evidence for a decision has accumulated.

3. A General Approach to Sampling

For either general sequential sampling or single sampling we could proceed as follows: Decide upon one level of quality or performance, which we may for the present think

of as "good" quality. Let this be q, and the hypothesis that the quality is at q be H_1. (The quality measure, q, could be average, standard deviation, fraction defective, etc.) Decide upon a second quality, q_2, which we will regard as "bad" quality. Let the hypothesis that the quality is q_2 be called H_2 or the "alternative" hypothesis. Also, for the present, we suppose that the only possible quality levels are just these two. Later we shall see that plans based on just these two work well for all other levels.

Next we must consider the risks or probabilities of erroneous decisions. If the H_1 is true, that is, the quality is at q_1, we might erroneously conclude that the quality is at H_2 and decide to reject H_1. This would be called an "error of the first kind". Let the probability of this error be α, that is, if the quality is q_1 the probability of rejection is α. Similarly, if H_2 is true, that is, the quality is at q_2, we can erroneously accept H_1, that is, conclude that the quality is q_1. This is called an "error of the second kind". Let the probability of committing such an error when H_2 is true be called β.

Now, in classical statistical tests, main attention was given to errors of the first kind. Tests were set up with fixed, small resks α, and the hypothesis, H_1, would be only rarely rejected when true. But, on the other hand, the quality might still be a long way from q_1, and we might easily still accept H_1. As a consequence, attention began to be paid to errors of the second kind. Early work, especially by E. S. Pearson and J. Neyman, led to the development of tests which had a fixed "error of the first kind", α, and which succeeded in minimizing errors of the second kind for one, many, or all possible alternatives. These were largely for single samples, that is, for a fixed sample size. Sequential sampling plans are "better" than such most powerful tests in the following sense: Suppose we take such a best single sampling plan with given α and n, then it is possible to find a sequential plan with the same α and with its maximum average sample size n, equal to n, but which has uniformly smaller probabilities of errors of the second kind. In other words, in this sense there are sequential plans more powerful than the most powerful single sampling plan.

Given the four quantities q_1 q_2, α, β it is possible in many cases to find single, double and sequential plans to meet these conditions. Always keep in mind that to compare two sampling plans as to cost and usefulness, we must first make sure that they supply comparable protection, that is, have similar operating characteristic curves. If the four quantities just given are the same, then the OC curves will be sufficiently alike for sound comparison.

Knowing that the OC (i.e. protection) curves are comparable, then we can look at the ASN, average sample number, (i.e. cost) curves. We can draw ASN curves for single sampling (a straight line) or double or sequential sampling plans. The latter tend to give the greatest saving over single sampling for quality outside of the interval between q_1

and q_2.

4. The Sequential Probability Ratio Test

We now consider Wald's basic sequential test. We form the ratio of the following probabilities from a sample of n:

P_{2n} = probability of the observed sample if hypothesis H_2 is true.

P_{1n} = probability of the observed sample if hypothesis H_1 is true.

Now our test is as follows:

If $P_{2n}/P_{1n} \leq B$, we accept H_1

If $P_{2n}/P_{1n} \geq A$, we reject H_1

If $B < P_{2n}/P_{1n} < A$, we continue.

The first makes sense because in this case we have worked until P_{2n} is so much smaller than P_{1n} that the explanation H_2 is so much poorer an explanation of the observed sample than H_1 that we are justified in accepting H_1. In the second case we have continued until the P_{2n} is so much greater than P_{1n} that H_2 is a sufficiently better explanation of our observed sample than is H_1, that we justifiably accept H_2 and reject H_1.

We now need to be able to set A and B to use a plan. These are determined by the type of case involved and by the risks α and β. In practice, however, α and β alone would determine A and B very closely. In fact we, in general, set

$$A = \frac{1-\beta}{\alpha} \quad , \qquad B = \frac{\beta}{1-\alpha} \quad . \tag{1}$$

Sequential plans with A and B so chosen actually will not have precisely the requested α and β, but will instead have risks, say α' and β'. It can be shown, however, that

$$\alpha' \leq \frac{\alpha}{1-\beta} \qquad \beta' \leq \frac{\beta}{1-\alpha}$$

$$\alpha' + \beta' \leq \alpha + \beta \quad .$$

It could still happen that one of the true α', β' obtained by using A and B as defined in (1) is a tiny amount above the respective α or β, but their sum is always less than or equal to the sum of the desired risks $\alpha + \beta$. Since the possible excess amount of risk of an α' or β' is extremely slight, we always do define A and B by equations (1), in practice.

Working out of the sequential plan for a special case depends upon the calculation of the ratio, P_{2n}/P_{1n} and comparison to A and B. In a number of important special cases, as we shall see, this can be simplified into a test with appropriate acceptance and rejection numbers for each sample size.

In many cases also, it is possible to find as many additional points to the OC curve, besides $(q_1, 1-\alpha)$, (q_2, β), as

we wish. Moreover, we find that although, technically, the plan was only worked out for the two quality levels, q_1 and q_2, it does give an OC curve making good sense throughout. Thus, as quality tends from q_1 toward q_2, th probability of acceptance (of H_1) decreases steadily from $1 - \alpha$ to β. Beyond q_2 it rapidly approaches 0, and beyond q_1 in the other direction, it rapidly approaches 1, or certainty. This is just what we would ask for. We only asked for the two points, but got all this too, a clear-cut case of "eating your cake and having it too".

The ASN curve is available, too, for special cases. In most of these cases it tends to hit a maximum somewhere between q_1 and q_2, but even at its maximum, it is well below the n for a single sample with comparable OC curve.

One other point which bothers some people is the possibility of a sequential plan running on forever. This has been proved to have a probability of zero. Thus, the plan is sure to terminate. In point of fact, the probability of a sequential sampling plan running on beyond three times the larger of the two ASN's respectively at q_1 and q_2 is very small. Hence, we usually only carry out the acceptance and rejection numbers about that far. Balancing such long runs are many quite quick decisions, which can even occur with $n = 1$.

A final general comment is that the probability ratio test does not depend upon our ability to handle the sampling distribution form as long as we can form P_{2n}/P_{1n}. This can be formed much more often than can we work out the precise single sampling test. We can, for example, make a sequential test of means with a very wide class of populations.

5. Comparison of Cases

We can easily handle the following cases by sequential analysis.

(a). Fraction defective, hypotheses on $q_1 = p_1 < q_2 = p_2$

(b). Number of defects per unit, hypotheses on $q_1 = c_1 < q_2 = c_2$

(c). Mean of measurements, one-way, σ' known, normal population, hypotheses on $q_1 = m_1 < q_2 = m_2$. Assume q_1 is acceptable.

(d). Mean of measurement, two-way, σ' known, normal population, hypotheses on $q_1 = m, q_2 = m \pm d$.

(e). Standard deviation normal population, mean known, hypotheses on $q_1 = \sigma_1 < q_2 = \sigma_2$.

(f). Same as (e), but mean unknown.

These five cases may then be summarized as follows:

(1). For case (a) we use the ordinary log of A and B to give a and b by

$$a = \log \frac{1-\beta}{\alpha} \qquad b = \log \frac{1-\alpha}{\beta} , \qquad (2)$$

while for cases (b) through (e) we use natural logs of A and B

$$a = \ln \frac{1-\beta}{\alpha} \qquad b = \ln \frac{1-\alpha}{\beta} \qquad (3)$$

(2). The test sample criteria are as follows, all of which are steadily accumulated:

(a). Total defectives, d in n pieces.
(b). Total defects, d in n pieces.
(c). Total measurements, ΣX or easier $\Sigma(X - A)$, coded data, in sample of n.
(d). Total deviations from m, $|\Sigma(X - m)|$ in n measurements.
(e). Total variation from true mean, m, $\Sigma(X - m)^2$, in n pieces.

(3). Criteria of acceptance and rejection, at sample size n, are all by formula respectively $-h_1 + sn$ and $h_2 + sn$, where $-h_1$ and h_2 are intercepts and s is the slope of two parallel lines. In case (d) there is a curving of the acceptance line, however, at small n's.

(4). Formulas, (be sure to use the correct a and b from (1).).

(a). $h_1 = \dfrac{b}{\log \dfrac{p_2(1-p_1)}{p_1(1-p_2)}} \qquad h_2 = \dfrac{a}{\log \dfrac{p_2(1-p_1)}{p_1(1-p_2)}}$

$$s = \left[\log \frac{1-p_1}{1-p_2}\right] \Big/ \left[\log \frac{p_2(1-p_1)}{p_1(1-p_2)}\right]$$

(b). $h_1 = \dfrac{b}{\ln c_2 - \ln c_1} \qquad h_2 = \dfrac{a}{\ln c_2 - \ln c_1}$

$$s = \frac{c_2 - c_1}{\ln c_2 - \ln c_1}$$

(c). $h_1 = \dfrac{b\sigma'^2}{m_2 - m_1} \qquad h_2 = \dfrac{a\sigma'^2}{m_2 - m_1}$

$$s = (m_1 + m_2) / 2$$

(d). $h_1 = \dfrac{\sigma'^2}{d}(b - .693) \qquad h_2 = \dfrac{\sigma'^2}{d}(a + .693)$

$$s = \frac{d}{2}$$

Use as criterion

$$\ln \cosh \left[\frac{d\,|\Sigma(X - m)|}{\sigma'^2}\right] \leq \frac{nd^2}{2\sigma'^2} - b$$

for small n, using tables in reference (3) for ln cosh fraction.

(e). $h_1 = \dfrac{2b}{\dfrac{1}{\sigma_1^2} - \dfrac{1}{\sigma_2^2}} \qquad h_2 = \dfrac{2a}{\dfrac{1}{\sigma_1^2} - \dfrac{1}{\sigma_2^2}}$

$$s = \frac{\ln (\sigma_2{}^2/\sigma_1{}^2)}{\frac{1}{\sigma_1{}^2} - \frac{1}{\sigma_2{}^2}}$$

(5). OC curves, probability of acceptance, L

(a). $p' = 0$ $\quad L_0 = 1$
$p' = p_1$ $\quad L_{p_1} = 1 - \alpha$
$p' = s$ $\quad L_s = h_2/(h_1 + h_2)$
$p' = p_2$ $\quad L_{p_2} = \beta$
$p' = 1$ $\quad L_1 = 0$

(b). $c' = 0$ $\quad L_0 = 1$
$c' = c_1$ $\quad L_{c_1} = 1 - \alpha$
$c' = s$ $\quad L_s = h_2/(h_1 + h_2)$
$c' = c_2$ $\quad L_{c_2} = \beta$
$c' = \infty$ $\quad L_\infty = 0$

(c). $\bar{X}' = \text{low}$ $\quad L_{\text{low}} = 1$
$\bar{X}' = m_1$ $\quad L_{m_1} = 1 - \alpha$
$\bar{X}' = s$ $\quad L_s = h_2/(h_1 + h_2)$
(bad for high values)
$\bar{X}' = m_2$ $\quad L_{m_2} = \beta$
$\bar{X}' = \text{high}$ $\quad L_{\text{high}} = 0$

(d). $\bar{X}' = \text{low}$ $\quad L_{\text{low}} = 0$
$\bar{X}' = m - d$ $\quad L_{m-d} = \beta$
$\bar{X}' = m$ $\quad L_m = 1 - \alpha$
$\bar{X}' = m + d$ $\quad L_{m+d} = \beta$
$\bar{X}' = \text{high}$ $\quad L_{\text{high}} = 0$

(e). $\sigma' = 0$ $\quad L_0 = 1$
$\sigma' = \sigma_1$ $\quad L_{\sigma_1} = 1 - \alpha$
$\sigma' = s$ $\quad L_s = h_2/(h_1 + h_2)$
$\sigma' = \sigma_2$ $\quad L_{\sigma_2} = \beta$
$\sigma' = \text{large}$ $\quad L_{\text{large}} = 0$

(6). ASN curve

(a). $p' = 0$ $\quad \text{ASN} = h_1/s$
$p' = p_1$ $\quad \text{ASN} = \dfrac{(1-\alpha)h_1 - \alpha h_2}{s - p_1}$
$p' = s$ $\quad \text{ASN} = h_1 h_2/s(1-s)$
$p' = p_2$ $\quad \text{ASN} = \dfrac{(1-\beta)h_2 - \beta h_1}{p_2 - s}$
$p' = 1$ $\quad \text{ASN} = h_2/1-s$

(b). $c' = 0$ ASN $= h_1/s$

$c' = c_1$ ASN $= \dfrac{(1-\alpha)h_1 - \alpha h_2}{s - c_1}$

$c' = s$ ASN $= h_1 h_2/s$

$c' = c_2$ ASN $= \dfrac{(1-\beta)h_2 - \beta h_1}{c_2 - s}$

$c' = \infty$ ASN $= 0$

(c). $\bar{X}' = \text{low}$ ASN $= 1$

$\bar{X}' = m_1$ ASN $= \dfrac{(1-\alpha)b - \alpha a}{(m_2 - m_1)^2}\, 2\sigma'^2$

$\bar{X}' = s$ ASN $= h_1 h_2/\sigma'^2$

$\bar{X}' = m_2$ ASN $= \dfrac{(1-\beta)a - \beta b}{(m_2 - m_1)^2}\, 2\sigma'^2$

$\bar{X}' = \text{high}$ ASN $= 1$

(d). Not available

(e). $\sigma' = 0$ ASN $= h_1/s$

$\sigma' = \sigma_1$ ASN $= \dfrac{(1-\alpha)h_1 - \alpha h_2}{s - \sigma_1^2}$

$\sigma' = s$ ASN $= h_1 h_2/2s^2$

$\sigma' = \sigma_2$ ASN $= \dfrac{(1-\beta)h_2 - \beta h_1}{\sigma_2^2 - s}$

$\sigma' = \text{large}$ ASN $= 1$

All of these formulas are quite readily obtained from the probability ratio definition and using the appropriate population functions. Case (f) is not so easily handled, but it turns out that we should use as criteria
$-h_1 + (n-1)s$, $h_2 + (n-1)s$, where the h_1, h_2, s are just as given for case (e) and where the criterion is $\Sigma(X-\bar{X})^2$. Note the large similarity in criteria formulas and OC and ASN curves.

Special approaches may readily be worked out to handle significance of difference between two proportions and between two means. These are also of much use especially in the laboratory.

6. Applications

The calculations of criteria of acceptance and rejection are not especially difficult to work out especially with appropriate tables and machines. Reference (3), part 2, contains a large number of special cases all worked out for case (a). Reference (4) has a set of cases worked out for cases (c) and (d) if $m_2 - m_1$ or d equal σ' and $\alpha = \beta = .10$.

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ACHIEVING QUALITY-MINDEDNESS THROUGH EMPLOYEE COMMUNICATIONS

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I have been asked to talk to you about a program which my company has conducted for the purpose of improving the quality of our products.

I am well aware that the chief interest of this group lies in the field of "Statistical Quality Control" and that you are all well versed on that subject.

My discussion, however, will not touch on "Statistical Quality Control." Instead, I want to tell you about another technique which I think is closely related to it. This technique has been used effectively by our company to improve the quality of our products, along with statistical methods. By supplementing the work you are now doing with statistical methods with some of the techniques we have used, you may be able to stimulate greater interest and obtain better results from your present program.

Our program is based primarily on the assumption that employee attitudes and quality performance go hand in hand. We feel that whether you use "Statistical Quality Control" or any other technique designed to improve quality, the whole thing can fall flat on its face if the real desire to improve quality is missing. And even though your present quality is considered to be good, it will be just that much better through the years if employees are quality-minded.

Before telling you about my company's program for achieving quality-mindedness, it is important to outline briefly the preliminary steps that we took to win the supervisors' and employees' acceptance of such a program.

First of all, much of the success of the program depends on whether the supervisors feel that they are in fact, as well as name, part of management. Our company set about specifically to do that with a comprehensive employee relations program built around the supervisor as the key man. Steps were taken to develop a better understanding between management and employees by telling them about company problems and giving them a chance to participate in various ways. This can best be done by having your director of personnel trained in this field or hiring an employee relations counselor to work with him. Some of the activities that will help create a receptive attitude for a good quality program are such things as:

- Service Award Dinners for 10, 15, 20 and 25 Year Employees
- Bulletin Board Information - Company news of interest to all employees
- Open House or Family Days
- Letters to Employees' Homes on subjects that affect the company and their own jobs.
- Employee Manuals on company policy and what they can expect from their jobs and what the company expects from them.
- Supervisor Conferences - Round table discussions about subjects supervisors deal with in their day-to-day work.
- Management Bulletins
- A Suggestion System
- Annual Interviews

In other words, there must be established a continuous flow of information about the company and its policies, problems and plans.

Having laid the groundwork for direct communication with employees, you are ready for a quality program.

We have seven manufacturing plants in various parts of the country, all of which manufacture wire and cable for electrical use. So we started by having each Plant Manager estimate the amount of savings he thought his factory could effect by a realistic effort to improve quality. All these estimates together totaled almost one million dollars. This amount of money, or even half of it, is certainly worth trying to save and thereby make our company more competitive on price. We, therefore, felt that we had a sizable goal to strive for.

Let me start out by stating the purpose of our Improved Quality program. Its purpose was to achieve and maintain improved quality in Anaconda Wire and Cable products, and by so doing reduce scrap, rework, and excess use of materials, which in turn will increase production efficiency and should increase customer acceptance, which in turn helps to create sales.

There were two chief objectives in this campaign, both stressing the human equation. First, to make every employee "quality conscious" by clearly defining to him just what Anaconda quality is -- which is making the best product at the lowest cost, using the materials and standards specified for that product. And to show our men and women the direct bearing that quality has on production, sales and job security, on the basis that improved quality actually costs less and improved quality makes sales and sales make jobs.

Second, to show every employee specifically how to get and maintain improved quality. This second objective dealt with specific problems of how to attain better quality.

This company-wide program ran for twelve months in each plant and it was conducted by using posters, letters to employees, publications, displays, slogan contests with local newspaper publicity, and scoreboards, in order to get the message across to the men and women in the shop.

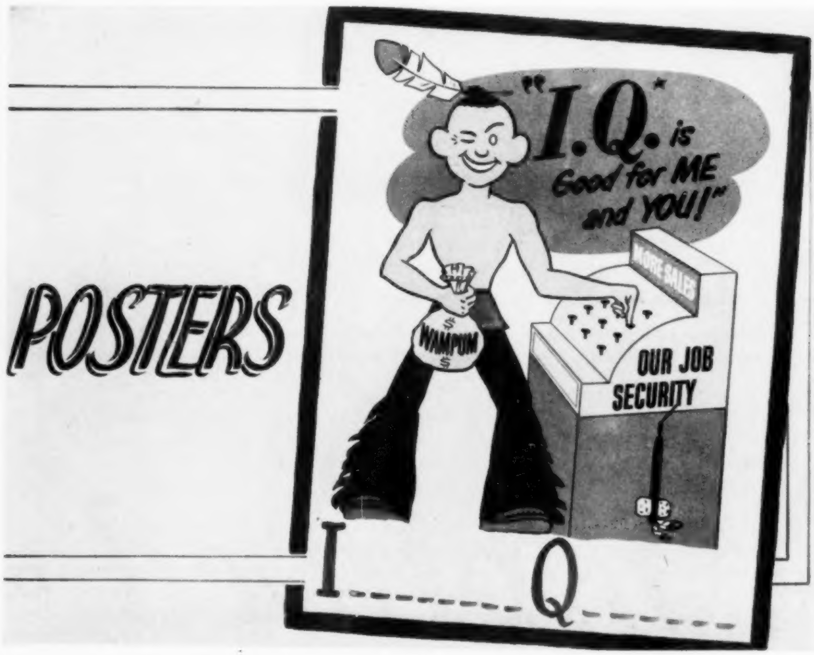
The program started in each of the plants with a personal presentation of the quality objectives by the Executive Vice President at a meeting of the management group in each plant. At this meeting, the local Plant Manager outlined to his supervisory staff the plant's objectives of a goal to achieve in terms of reduction of scrap, rework and excess use of materials, and announced the selection of a Quality Committee to direct the program in the plant. The Headquarters Quality Control Department administered the program and handled the details of coordination, assisted by our Industrial Relations Department and a consultant in the field of Industrial and Community Relations.

Let me explain the conduct of the campaign. First of all, the program started with a teaser poster campaign to arouse interest. A series of three posters were used. These posters were placed in each department in each plant at two-day intervals. The first poster featured the question, "How's Your I. Q.?". The second poster, appearing two days later, read "Sure, a High I. Q. Leads to Success". Two days later a third poster explained for the first time the meaning of the letters "I. Q.", which is Improved Quality.

On the day the meaning of "I. Q." was revealed on the posters, each Plant Manager sent a letter to each employee's home explaining the purpose of the campaign and stressing the importance of quality as it affects job security and seeking the assistance of each employee in improving quality.

After this teaser poster series, a fourth poster emphasized the relationship of Quality, Sales and Job Security, and this poster remained for a longer period of time in the various departments, and then was replaced with other posters from time to time carrying a similar message.

So much for the build-up.



Now here is the guts of the program.

Special "What Happened" displays were set up periodically in the various departments to dramatize the causes of rejections and to show how they could be prevented. These posters were used to point up specific production mistakes over which the operator had control and then showed him how to avoid similar mistakes in the future. With each example of poor workmanship, several constructive points were made which should help to prevent a recurrence of the condition displayed. In some cases, actual customer complaints were dramatized. During the program over 300 of such displays were made. Another poster was displayed whenever there was occasion to give a department or plant a pat on the back.

Another important promotional device was the use of I. Q. Tips. These were used by supervisors in each department to carry a message over his own signature through posting it on the bulletin board in his department. These I. Q. Tips carried specific messages to the operator through the written word of the foreman to supplement his oral instructions in securing satisfactory workmanship. Over 300 of these messages were posted.

Scoreboards were set up in the individual departments to keep the employees advised of their progress in cutting down rejects and spoilage in improving the department's quality record. Most of these scoreboards were on a weekly basis. In addition, each plant had a plant-wide scoreboard which totalized the progress of the campaign toward achieving the plant's goal in terms of reduction in scrap. Here is an example of one.

These scoreboards were maintained on a monthly basis in such a manner that the results of each month's efforts showed the pounds of scrap produced to the pounds of material put into production, compared with the previous month's record and the goal to be achieved.

In order to develop interest in the job, other displays were made to show the end use of our products, both by pictures and by the actual equipment in which our products are used. These displays were very

effective in bringing home to our men and women the importance of quality of our products in the successful running of machines and equipment that each of us uses in his daily life. Many of these displays were loaned to us by our customers. Here is where our Sales Department participated. It gave them an opening to talk I. Q. to some of our good customers in order to obtain material to assist the program. Pictorial displays of Anaconda wire in use were posted regularly in all departments.

Raw material displays were made to develop greater interest in the materials our men handle every day and to drive home their cost to encourage them to reduce waste. There were 21 different raw material displays.

During the progress of the campaign, a publication was issued called I. Q. NEWS, devoted to the news of the campaign. The purpose of the publication was to provide an exchange among plants for improving quality and to keep enthusiasm and interest at the local plant at a high level. A copy was sent to each employee's home about once a month.

Management News Bulletins carried messages to supervisors from the Executive Vice President concerning the progress in each plant.

In the regular established suggestion system, double awards for suggestions which improve quality were given during this campaign.

A slogan contest was conducted in each plant with a $25 prize going to the winner. Some plants gained favorable publicity on this through the local papers. The winning slogan in each plant was used very effectively in displays and on posters.

The Quality Committees in each plant in addition have shown a lot of ingenuity to keep interest alive. For instance in one plant a fluorescent plexiglass "I. Q." sign was installed at the time clock, and across the face of each time card was stamped the slogan, "Quality First in All We Do". Another plant used a slogan printed on each employee's time card. It said "Work for I. Q. - It will work for you". At still another plant each production order carried a sticker which said "Put I.Q. in all you do".

Even though this campaign was designed primarily to appeal to the operator, we were impressed with the interest shown by supervisors. For instance, at one plant the foreman of the Stranding Department developed a better means for matching lengths of conductor by using a diameter, weight and length table. This reduced the amount of scrap at the stranders.

In another plant the Assistant Superintendent reported that through their periodic foremen's meetings on scrap, they have analyzed scrap to the point where they have more knowledge of what is normal scrap per spindle than they have ever had before.

At still another plant the Superintendent reported concerning the increased interest of foremen in the problem of reducing scrap by his frequent reference to department scoreboards and through periodic meetings.

This, of course, was also true at another plant where before this program started the Superintendent had been making an intensive drive for increased quality on the supervisory level. His program went forward hand in hand with the I. Q. campaign, with very definite gains made.

At each plant the Manager or Superintendent had regular meetings with the Quality Committee to discuss the activities of the campaign.

There were many instances in all the plants which showed an increased interest by everybody in the factors being stressed in this campaign.

The important question is - what has been accomplished? This is a very difficult thing to evaluate since there are so many factors that enter into it. For instance, a reduction in the use of excess material effected by Statistical Quality Control activities in the various plants has contributed to progress toward the goal. And then, of course, the amount of savings made in rework is difficult to analyze except over long periods of time. Furthermore, this is important - no one will ever be able to measure in dollars the amount of customer good will gained because of improved quality.

Well now, how much, if any, of that goal was achieved in this I. Q. campaign? In order that we can have some idea of possible effects of this program, an analysis of the business statements of the various plants was made to determine the actual scrap cost during the year compared with the previous year. This analysis indicated a large dollar saving for our company. The individual Plant Managers reported their estimated savings in rework and material costs. The total of these figures showed an achievement of 68%. However, if adjustment is made for volume of business, it represents an achievement of 81%.

I've talked a lot about scrap reduction and you may get the idea that this was a scrap drive. Well, we were using scrap as an indicator because there is a close relationship between preventable scrap and the general level of quality. The fewer defectives we find in inspection means the less chance that the customer will find defective material in the shipments he receives from us.

Another indication of results is the fact that there has been a reduction of 25% in the number of substandard reports issued by the Inspection Department during the 12 months over the preceding 12 months.

Even though the program was designed to appeal to the men on the machine, it had a very fine influence throughout the whole organization. But probably most important of all is that we have succeeded in developing habits and attitudes toward quality which we feel will be with our company for a long time to come.

DESIGNING EXPERIMENTS TO ISOLATE SOURCES OF VARIATION

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An experimenter, immersed in the detail of carrying through his experimental procedures, may easily forget that the interpretation of his results will depend on an abstract pattern or model. Usually the model contains assumptions which cannot safely be accepted without evidence, yet conclusions cannot be drawn from the experimental results without assurance that the assumptions are valid.

The theory of experimental design deals with questions such as these, with models which can serve as patterns on which experiments and their interpretation can be based and with the planning of experiments which will conform to these models or, at least, will test their validity.

It is proposed here to discuss these ideas, through the manner in which they bear on an illustrative experimental situation.

Let us suppose that we wish to compare the wearing qualities of two types of automobile tire (assuming that we have a means of measuring wear) by running them on the same car at the same time. If we have two tires of one type (A) and two of the other (B), it may be possible to mount these four tires on a car and, by making wear measurements, to obtain a legitimate comparison between tires A and B. What factors must be taken into account and what conditions must be fulfilled in order that the comparison be, in fact, legitimate and how must the test be conducted so that we may test to be sure that these conditions really are satisfied?

Some of the factors are surely well known. We know, for example, that tires on the front wheels of a car are likely to wear at a different rate from those on the back wheels. It seems likely, also, that the rates of wear are different on the two sides of the car. Beyond these facts or guesses, our experience does not carry us.

Now, among the four wheels of a car there are three independent comparisons, that is, three degrees of freedom. In the light of what has been said, we would choose to think of them in the following terms.

(α) Front vs. rear; in symbols, we might represent this by
$$(LF) + (RF) - (LR) - (RR).$$

(β) Left side vs. right side;
$$(LF) - (RF) + (LR) - (RR).$$

(γ) The interaction of (α) and (β);
$$(LF) - (RF) - (LR) + (RR).$$

If, for example, the two A tires were mounted on the front and the B tires on the rear, the difference between the two types of tire would be identified with (α) and could not be distinguished from a difference between front and rear. This would be an intolerable experimental plan, of course. The same sort of reasoning would prevent us from putting both A's on one side of the car and both B's on the other, which would identify the difference between tires with (β). The only remaining possibility is to

identify the difference between tires with (γ), which puts one A and one B on each end and one A and one B on each side. It must be granted, though, that we have no real assurance that (γ) does not receive important contributions from differences among the four positions and if we were to run a test according to this plan, we would have no way of knowing whether differences among tires, or differences among wheels, or both were contributing to the observed value of (γ). This plan, then, is unsatisfactory, since it fails to provide a check on the assumption that (γ) receives no persistent increment from differences among wheels. It appears, therefore, that no test based on one car alone can measure up to our requirements for an acceptable experiment.

If we can use two cars and four tires of each type, a somewhat better plan can be made up. We now have seven degrees of freedom, one of which must be identified with the difference between tires and the one to be so identified is wholly subject to our choice. Let us lay out the seven degrees of freedom with a view to selecting the "safest" one.

Table 1

	$(LF)_1$	$(RF)_1$	$(LR)_1$	$(RR)_1$	$(LF)_2$	$(RF)_2$	$(LR)_2$	$(RR)_2$
(a) Car 1 vs. Car 2	+	+	+	+	-	-	-	-
(α) Front vs. Rear	+	+	-	-	+	+	-	-
(β) Left vs. Right	+	-	+	-	+	-	+	-
(γ) = ($\alpha \times \beta$)	+	-	-	+	+	-	-	+
($a \times \alpha$)	+	+	-	-	-	-	+	+
($a \times \beta$)	+	-	+	-	-	+	-	+
($a \times \gamma$)	+	-	-	+	-	+	+	-

In making a choice of the component with which to confound the difference between tires, we see that (a) is clearly unsuitable and (α), (β) and (γ) have already been considered and rejected. The component ($a \times \alpha$), the interaction of the front-rear difference with cars, may well represent a genuine difference among wheels, because, for example, it is quite possible that front tires wear faster than rear tires on one of the cars, while the reverse holds for the other car. Presumably, then, we would not choose to entangle the comparison between tires with this component. Similar arguments stand in the way of using the component ($a \times \beta$). We are left, then, with component ($a \times \gamma$), which represents the second-order interaction between cars, front vs. rear and left vs. right. We cannot, it is true, be certain that this component receives no real contribution from differences between cars and between wheels, but at least it is more likely to be free from such contributions than any of the other components.

The allocation of tires to wheels that will confound the difference between types of tire with the component ($a \times \gamma$) can be read from the line of the above table that specifies this component, by associating one type with the plus signs and the other with the minus signs. For example, we may put A tires on $(LF)_1$, $(RR)_1$, $(RF)_2$, $(LR)_2$ and B tires on the other wheels.

An experiment conducted according to this plan could succeed, in the sense that we could have assurance that no persistent differences between wheels have entered into the component that exhibits the difference between types of tire. This would be the situation if, for example, the component ($a \times \beta$) proved to contain nothing beyond what experimental error could account for, which would mean that differences between sides are the same on the two cars. In this event, the ($a \times \gamma$) component could contain nothing except differences between tires and, of course, experimental error. On the other hand, the plan would fail to give us this assurance if both components ($a \times \alpha$) and ($a \times \beta$) proved to contain substantially more than experimental error. In this circumstance, while we could not assert that the ($a \times \gamma$) component did reflect differences among wheels, we could not be sure that it did not.

Evidently, if we desire further insurance against obtaining results which do not furnish a clear-cut and confident interpretation, we shall have to bring more cars into the experiment. Let us suppose that we can equip two more cars with A and B tires in exactly the same arrangement as was used with cars 1 and 2. This amounts to a complete repetition of the experiment envisaged with the first two cars, although it may not be a "replication" in the statistical sense.

When the fifteen degrees of freedom now available are laid out (Table 2), it is perceived that only one of the three degrees of freedom which make up the second-order interaction is used to estimate the difference between tires, leaving the other two free to exhibit whatever real interaction there may be. This experiment, then, contains a highly important element, a provision for testing an assumption upon which the interpretation of the experimental results must depend.

One further question must be settled. Every experimental plan must furnish a definition of experimental error and make provision for estimating its magnitude. In the example we are discussing, the definition of experimental error seems to be not wholly obvious. It is proposed that we define experimental error as the content of those second-order interactions which are not confounded with types of tire. The experimental plan based on Table 2 then furnishes at once a means of estimating the contribution of experimental error. There are, however, only two degrees of freedom designated for this purpose. This number could be increased only by increasing the number of cars.

This definition of experimental error requires that we modify the view that has been adopted up to this point. Throughout the earlier discussion, we took the position that some of the differences among cars and among wheels might filter through to the second-order interaction, where we proposed to make our comparison between types of tire and we were concerned simply to learn whether this did, in fact, happen. For this purpose, the components ($b \times \gamma$) and ($c \times \gamma$) were provided. Now, when we propose to use these components to define experimental error, we must take steps in the conduct of the experiment to ensure that no real contributions from differences between cars and wheels reach the second-order interactions. Naturally, this decision places the responsibility for producing a successful experiment on the shoulders of those who carry out the experiment. It is not easy to say just what precautions should be taken to ensure the

<u>Table 2</u>

	A $(LF)_1$	B $(RF)_1$	B $(LR)_1$	A $(RR)_1$	B $(LF)_2$	A $(RF)_2$	A $(LR)_2$	B $(RR)_2$	A $(LF)_3$	B $(RF)_3$	B $(LR)_3$	A $(RR)_3$	B $(LF)_4$	A $(RF)_4$	A $(LR)_4$	B $(RR)_4$
Between cars																
(a) 1, 3 vs. 2, 4	+	+	+	+	-	-	-	-	+	+	+	+	-	-	-	-
(b) 1, 2 vs. 3, 4	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-
(c) 1, 4 vs. 2, 3	+	+	+	+	-	-	-	-	-	-	-	-	+	+	+	+
Between positions																
(α) Front vs. Rear	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-
(β) Left vs. Right	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
(γ) = (α x β)	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+
Cars x positions																
(a x α)	+	+	-	-	-	-	+	+	+	+	-	-	-	-	+	+
(b x α)	+	+	-	-	+	+	-	-	-	-	+	+	-	-	+	+
(c x α)	+	+	-	-	-	-	+	+	-	-	+	+	+	+	-	-
(a x β)	+	-	+	-	-	+	-	+	+	-	+	-	-	+	-	+
(b x β)	+	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+
(c x β)	+	-	+	-	-	+	-	+	-	+	-	+	+	-	+	-
(a x γ)	+	-	-	+	-	+	+	-	+	-	-	+	-	+	+	-
(b x γ)	+	-	-	+	+	-	-	+	-	+	+	-	-	+	+	-
(c x γ)	+	-	-	+	-	+	+	-	-	+	+	-	+	-	-	+

The component (a x γ) exhibits the difference between tires A and B.
All other components are independent of this difference.

validity of our definition of experimental error, but it seems reasonable to suppose that we might use cars of the same make and model, check on alignment and wheel balance, control the mileage of the test and the like.

In conclusion, it may be helpful to see the results of a test conducted according to the plan of Table 2. Wear was determined by measuring the depths of the two central grooves of the tire by means of a suitable instrument. The following analysis of variance table was calculated from coded values of such measurements made at the beginning of the test and again after 700 miles of wear.

Table 3

Source of Variation	Degrees of Freedom	Mean Squares
Between cars		
(a)	1	1668
(b)	1	20
(c)	1	536
Between positions		
(α)	1	751
(β)	1	26
(γ)	1	0
Between cars x (α)	3	489
Between cars x (β)	3	113
Between cars x (γ) (error)	2	27
Between tires	1	8548

QUALITY CONTROL MEANS LESS SALVAGE AND SCRAP

Robert B. Griffith
The Bossert Company
Division of Timken-Detroit Axle Co.

Companies of all classes and types are becoming more aggressive and alert in that they have discovered a way to get ahead in these days of ever increasing competition. They are doing this by reducing production costs and lowering repair costs, which ultimately means a drastic reduction in the percentage of products that do not conform to specifications.

The question is raised - How can this be done? The answer is simply by establishing some sort of quality control program. This in itself will enable the inspection department to operate more efficiently by applying the laws of probabilities to its inspection procedure, thereby preventing the accumulation of large percentages of defective material at final inspection or at the customer's plant.

The normal procedure in past years, and unfortunately to a large extent today, is that companies do rely on final inspection to sort out any defective material that has been made and accumulated through the various stages of production.

Final inspection can at its best only indicate percentages of substandard material that is sorted out but it cannot relate to management what causes these defects or whether the equipment can produce within the prescribed tolerances. To determine the causes of defects after the products are completed is in most cases costly and time consuming. Anyone who has ever had anything to do with final inspection recognizes that such an operation is monotonous which, in itself, tends to promote inefficiency. This monotony element is particularly strong in visual inspection where the inspector must compare each piece with a subjective standard and make as many judgments as the number of pieces inspected. The percentage of correct judgments is usually fairly low, (60% to 70% is often stated as overall accuracy of visual inspection).

An example in our plant under controlled conditions will bear out the irregularity of 100% visual inspection. We have been for sometime visually inspecting the surface of an aluminum stamping for nicks, dents, wheelmarks, and scratches, anyone of which is a critical defect thereby causing the stamping to be rejected. On a long run of 275,000 pieces, 31.1% were rejected on the first inspection and 10.5% rejected after a second inspection still resulting in 6% to 15% getting through to the customer. The problem in this case was to guarantee a 2% A.Q.L. (Average Quality Level) which was impossible to do when we were getting such a low degree of efficiency in our inspection, and rightly so, as it is a normal condition. So rather than take further chances on the accuracy of our visual inspection which must continue, we applied a sampling plan that would guarantee this 2% A.Q.L. to lots of 500 pieces or more after the screening operation. Several times during the course of production, lots were rejected prior to shipment, yet since the application of this sampling technique we have not had any Vendor complaints.

On the other hand, a higher level of accuracy is usually assumed for gaging inspection; yet, tests do not always support this assumption. The use of complex measuring instruments has been analyzed by a study published in the December 1945, issue of "Journal of Applied Psychology" under

the title of "Accuracy of Precision Instrument Measurement". It stated that inspectors using standard 3" micrometers were accurate within plus or minus .001" sixty-four per cent of the time and in using depth micrometers only fifty-three per cent could check within plus or minus .001".

It would appear, therefore, that a replacement for the inefficient sorting of good from bad after a lot has been produced would represent industrial progress. The progressive replacement is quality control which means exactly what the name implies--that products are controlled from the first productive operation on through to the last operation, which makes certain that these products conform to the specification set up by the manufacturer. Again, this means that the quality control department does not wait for final inspection to discover the defects, but by the application of its sampling plans and control procedures, finds the defects as they occur at the various productive operations.

Let's go back and consider the high cost of final inspection which should include salvage and scrap cost, plus customers' charges, (this concerns the products that must be salvaged by the customer in order to make them usable).

From the standpoint of economy, we find that the substandard product sorted out at final inspection is going to cost that much more to scrap because of extra operations plus the time and material added after the defect was produced. To illustrate this point, during the production of compressor shells we found that 139 shells out of every thousand produced were defective but still continued on through all the operations and were rejected at final inspection. By a simple application of Quality Control we were able to reduce this defect to 38 shells per thousand which represented a saving of $22.93 per thousand. The material that is sorted out for repair may be borderline and not salvageable hence, must be scrapped. Again, to repair in the finished state often requires more time whereas it could have been repaired much cheaper in the prefinished stage.

In order to show what can be done as a result of revamping the inspection department from a final inspection to a quality control department, I will submit facts pertaining to our own plant that will tend to indicate what can be done in a short time.

Prior to the initiation of a quality control program in any plant, it is necessary to know what the company has done costwise for at least one year previous to the control inaugural in its salvage, scrap, inspection, and one other account that we use in our company, namely "Customers' Quality Account". This particular account concerns the cost our customers charge to make defective parts usable.

These accounts can be called quality indicators, because that is just what they do: Measure the plant quality in percentages of Direct Labor.

Scrap and Salvage measure the efficiency of production.

The Customers' Quality Account measures the ability of the inspection department to evaluate properly the defect as it occurs plus its effectiveness in catching the defect before it is shipped out. This bears out the old adage that "quality must be built into the product; it cannot be inspected there".

Our plant inspection before Quality Control was similar to many others

in that we had a first piece inspection, three roving inspectors for two shifts who made hit and miss inspections once or twice a shift, and last but not least, a group who did nothing but sort out everything produced prior to shipment, namely, final inspection.

At the start of our program, my yardstick was as follows: Inspection cost - 18.34%, Scrap - 8.5%, Salvage - 20.6%, Customers' Quality Account - 2.78%.

The graphical trends of these overhead accounts were definitely not in a state of statistical control and would require some drastic action to reduce them to a state of normality.

The inspection department was changed completely by reducing the final inspection section by as many men as it took to staff the floor inspection at the ratio of one Quality Control operator to every twelve machines, and by operating on the principle that the work found bad between periodic inspections would be sorted out and the balance would be shipped out as approved by the Quality Control operators. Quality Control charts were put up on all operations and maintained by the Quality Control operator along with a separate quality record which was turned over to the Quality Control Department for evaluation and dissemination.

At the end of the first year of control, the quality yardstick indicated the following results: The Salvage yardstick decreased from 20.6% to 9.5%, or an accumulated saving of $71,140.13, the Scrap yardstick decreased from 8.5% to 5.34%, or an accumulated saving of $33,677.96, and Customers' Quality Account decreased from 2.78% to 0.56%, or an accumulated saving of $11,802.66. Inspection costs were also reduced from 18.34% to 16.47%, and today are approximately 14.7%. Money of this kind does not appear in the accounting system by waving a magic wand. The essential sequence is: A survey of the existing situation, a thorough understanding of all parts of the production operation, careful planning of a campaign for improvement, and finally action. Perhaps the most illuminating thing I can do at this point is to present in some detail the implementing of this sequence for one of our volume production items, and to show the results obtained.

During August, 1950, Quality Control techniques as applied to manufacturing and inspection, were introduced at the Bossert, Utica Division of the Timken Detroit Axle Company.

One of the first processes analyzed was the fabrication of this compressor shell as shown in figure 1.

These shells are made from hot rolled, pickled and oiled S.A.E. 1010 steel sheets .125 thick.

The fact was recognized that this item was costly to process due to excessive repair and scrap. In addition, continual customer complaints resulted from the poor quality.

During the period of September 1949, through August 1950, 173,000 shells were produced with 25% (about 43,000 pieces) requiring repairs of one sort or another. This repair cost in our own plant amounted to 24.9% of the Direct Labor on this particular job. In addition to this cost we had a customers salvage charge of $5400.00 which was way out of line and certainly did not help our good will any.

Figure 1

Realizing the above situation was intolerable, control charting was applied to the various processes — blanking, drawing and forming — with the aim of localizing and eliminating each defect in fabrication.

Where a "variable" was involved (that is, an item that can be measured) X and R charts were set up.

With an "attribute" (that is, a characteristic that can't be measured, such as burrs, rust or dents) "P" charts were started.

The following defects were responsible for the unreasonable repairs and the poor quality:

(1) Shallow draw - causing finished shells short in height.
(2) Repickle - rusty.
(3) Dents.
(4) Burrs in punched holes.
(5) Scoring and gouges.
(6) Breakage - splits or broken during drawing or forming operations.
(7) Dimensional inaccuracy - oversize on the $6.5035 \pm .0015$ dia.
(8) Dimensional inaccuracy - oversize on the $8.565 \pm .005$ dia.

Three of the above eight items were immediately plotted on a PN chart; namely, shallow draw, scoring and gouges, and breakage. Here is the PN chart for the draw operation controlling the height on Press #64. (see figure 2)

This chart covers the interval from 9-5-50 through 9-16-50, and during this span the following discrepancy items were detected at the regular control checks every 30 minutes:

Item 1 (9-6-50)	Uneven draw - scalloped and about 20% breakage.
Item 2 (9-7-50)	Breakage 7%.
Item 3 (9-8-50)	Breakage still excessive - Load on pallet removed from production.
Item 4 (9-8-50)	Scalloped draw - Load on pallet removed from production.
Item 5 (9-8-50)	Scored.
Item 6 (9-8-50)	Uneven draw - Load on pallet removed from production.
Item 7 (9-12-50)	Loose punch.
Item 8 (9-12-50)	Reset Hold down.

At this time it would be in order to point out that a Q. C. chart at the machine, or at the bench, presents a picture of just how well the machine or the tools are doing the job they were designed to do.

But the chart can't get out of its holder and correct a die, remove a slug on a punch, or tighten a loose punch. However, it does indicate when action is required to keep a job or process within specification.

It can, through the operator, supervisor, and control man, get word to authorized people with "know how" that something is wrong that must be corrected.

The Manufacturing and Tooling Divisions got behind the eight items causing scrap and rework and effected corrections that contributed to the substantial savings eventually realized on the fabrication of this compressor shell.

Current "P" charts show continued improvement in quality, with still lower costs.

Determining process capability and dimensional accuracy for the 6.5035 $\pm$ .0015 and 8.565 $\pm$ .005 inside diameters indicated the use of X and R charts as the variable lent itself very nicely to accurate measurement with proper checking equipment.

Thus precision dial bore indicating checking gages with master rings ground to 6.5035 and 8.565 were provided.

With this equipment the control operator was in a position at Press #49 to check a 5 piece sample every hour and plot the results on the control chart.

See figure 3, for the original X and R chart for the 6.5035 diameter.

Let's discuss this original chart.

The scale to the left in the averages graph is divided into increments or cells of .0005. The spread, 6.502 to 6.505, of course, indicates the drawing tolerance.

The range scale extends to .003, the drawing tolerance spread.

The chart has the average and range control lines set at a predetermined position controlled by the sample size and the tolerance.

This method of predetermining and positioning the control lines greatly simplifies the task of control charting. In addition these lines indicate at once the control bands which guide manufacturing in producing quality.

Operators, control people, and supervision can tell at a glance whether a process is in control or out of control.

The date and time of check is systematically recorded. The different colored dots indicate the change from one shift to another.

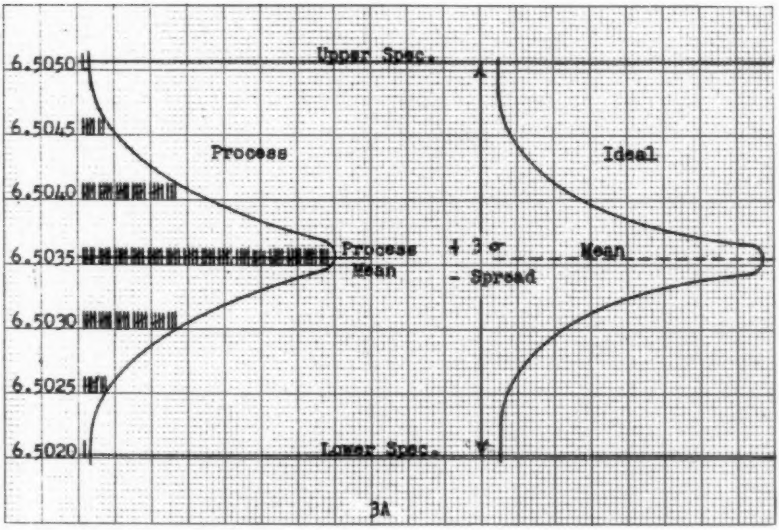
Although the colored dots cannot be seen at this time, it is standard practice in all Timken-Detroit Axle plants to use Green for the day shift- - Red for the second shift -- Blue for the third shift control checks.

This chart showed immediately that many pieces were being produced oversize on the 6.5035 diameter.

Some comments on process capability

To produce the maximum number of parts within specification with a minimum of scrap and repair, a process must be centered on the mean dimension of the blue print. In addition, the natural variations in dimensional accuracy from piece to piece must be reduced to the extent that the + and - 3 sigma band coincides closely with the upper and lower limits of the specification. This determination involves the calculation of the standard deviation, mean, and the + and - sigma band.

Here is an example of ideal process capability:



Note these items in above example:

1. Both curves are normal.

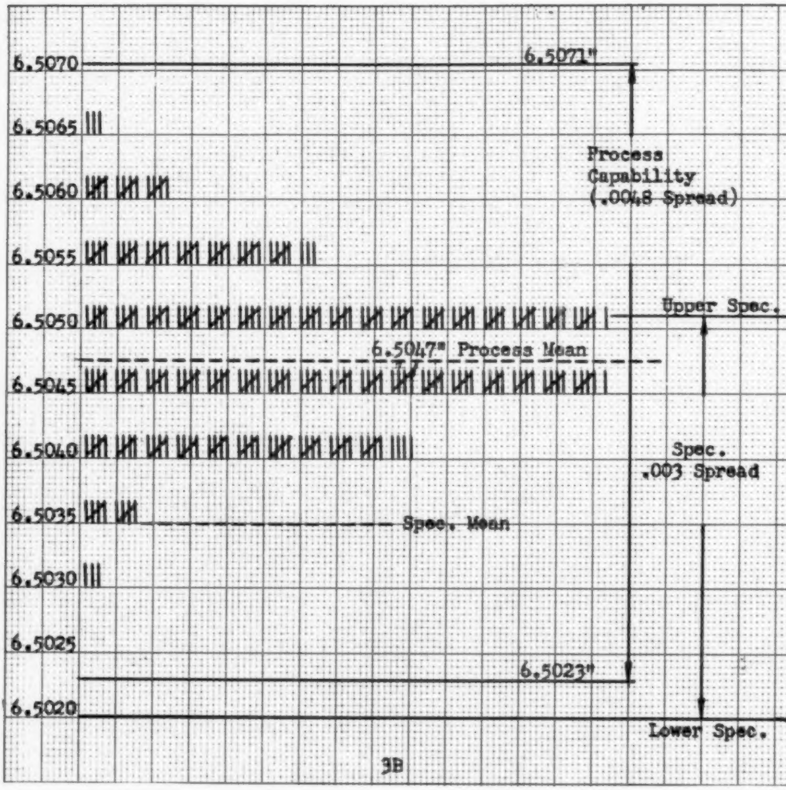
2. Drawing mean and process mean are identical.

3. Both means are positioned at the exact center of the specification.

4. The $\pm$ 3 sigma boundary of the process measurements coincide closely with the specification upper and lower limits.

This sort of reasoning can be applied to any process and is known as analyzing process capability. The above example demonstrates a very ideal condition.

Let's analyze the frequency distribution of the individual measurements as recorded on the X and R Control Chart.



From the practical aspect the distribution is normal, indicating the absence of unnatural process variations from piece to piece.

The standard deviation or sigma is .0008 with the process mean positioned at the 6.5047 dimension.

Extending the $\pm$ 3 sigma band from the process mean indicates a process spread of .0048. Comparing this process capability with the tolerance spread of .003 indicates the possibility that the present methods and tooling cannot hold a .003 tolerance.

With a process centered close to the high limit of a specification rather than on the mean dimension, it is natural to expect that approximately 50% of the parts produced would be oversize.

Obviously this fact indicated the necessity of reworking the forming press die to smaller dimensions or precisely to the extent that the process mean would be the same as the specification mean dim.

This analysis proved the necessity for some corrections to the forming die so the corrective action indicated was taken, namely reworking the die.

The notes on the chart point out that the control man was trained to observe discrepancies, such as burrs, scratches, and improper coining. A well trained control man considers this overall examination an important part of his work. He is continually searching for poor finishes, improper chamfers and radii, burrs and chips, mutilations, etc. He reports such findings on the control chart and points these out to the operator and foreman.

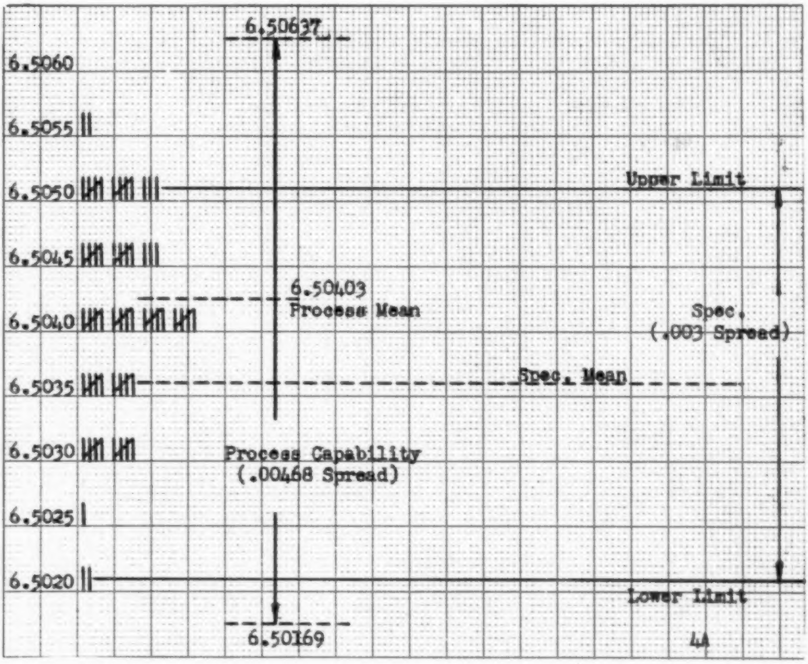
Figure 4 shows a control chart for the same dimension after some correction was made to the die.

This chart shows much improvement in the quantity of parts being produced within specification, although the process mean still is not on the specification mean.

Again let's analyze the frequency distribution of the individual measurements as recorded on the control chart after some corrections were made to the process.

This chart has 2 frequency distributions indicating 2 different parts with the same inside diameter.

The frequency distribution for part number 19442-58 indicates the following information:

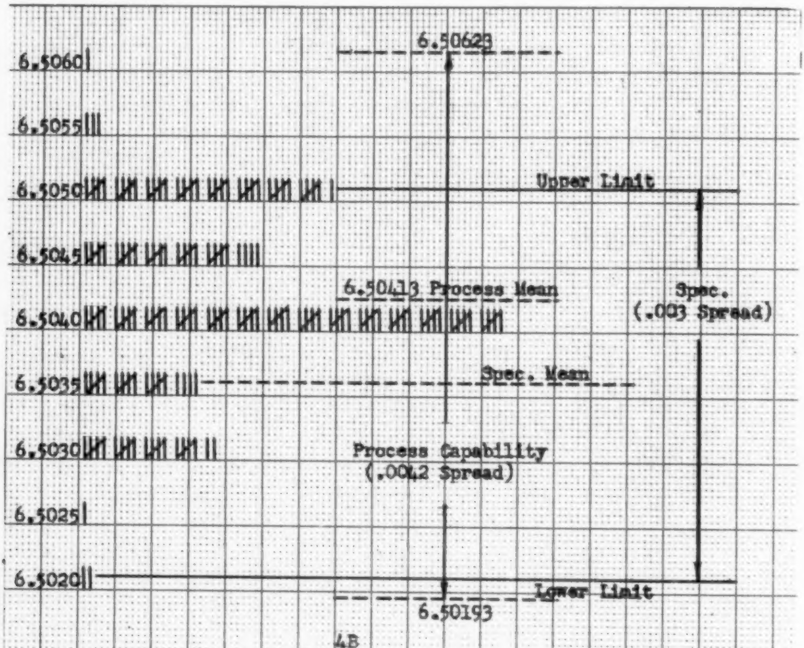


From the practical viewpoint this distribution can be considered sufficiently normal (although slightly skewed) for process capability analysis. A sample size larger than 71 pieces (100 pcs. or more) of course, is more desirable.

The process mean has been lowered to some extent by reworking the die. Originally the process centered on 6.5047 - now on 6.50403" - a drop of .00067". This drop indicates many more pieces produced within specifications, also a nice reduction in repair and scrap. Originally 54% of parts produced were oversize. This item is now reduced to 10%, and can be further improved by additional corrections to the forming die and bringing the process mean still closer to the specification mean.

Analysis of 2nd frequency distribution.

Frequency distribution - Part Number 19493 - 44 & 45



The analysis of this distribution substantiates the information indicated by the preceding distribution, showing considerable improvement in dimensional accuracy with the resultant lower scrap and repair costs.

Controlling the 8.565 inside diameter

The 8.565 ± .005 inside dimension formed on Press #49 varied considerably from specification with many pieces oversize.

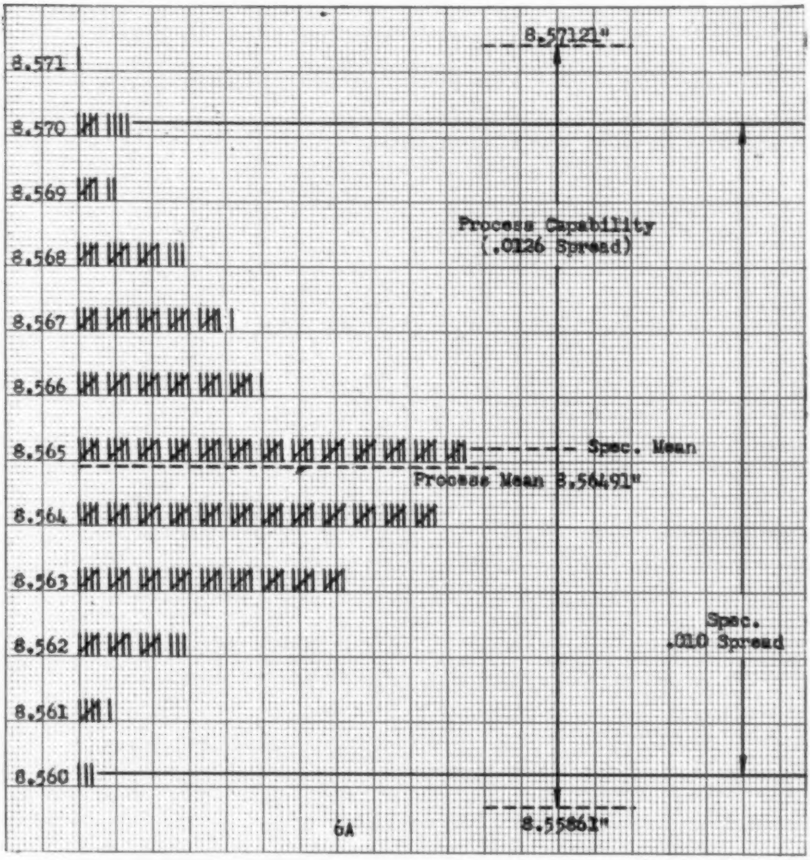
Figure 5 shows the first X and R chart on this operation.

Die was plated .0025 to reduce the high process average. Ranges were O. K. indicating a process that could hold dimensional accuracy if properly centered.

Figure 6 shows a later control chart on the 8.565 ± .005 inside dimension.

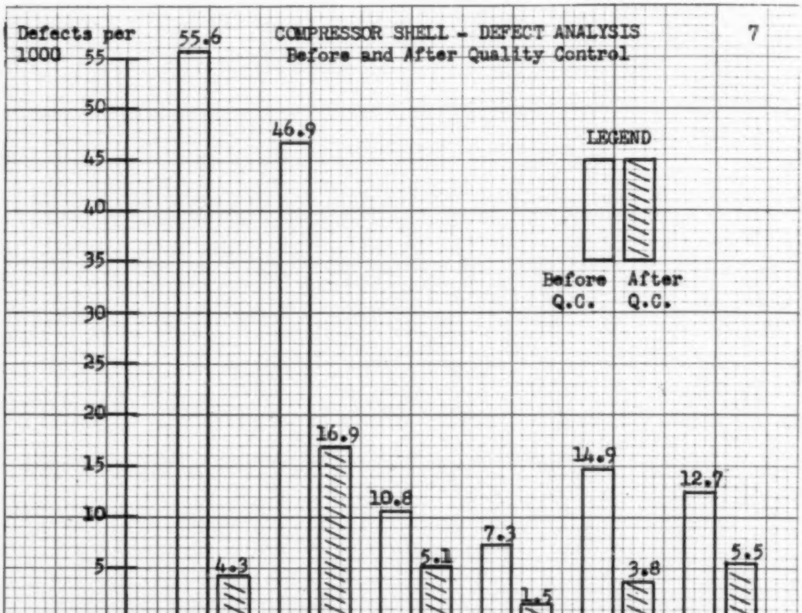
We recognize immediately that the corrections made (when was plated .0025) resulted in improved dimensional quality.

Let's analyze the frequency distribution on this chart.



For all practical purposes this distribution can be considered normal. The process mean coincides very closely to the drawing mean indicating an operation well centered. The process capability is slightly larger than specification and should be reduced to .010 if at all possible. If not, the Engineering tolerance on the 8.565 dim. should be changed to ± .006 instead of ± .005, thus opening up specifications to process capability.

Let's examine this bar chart showing the improved quality on the compressor shell item after Quality Control started:



Type Defect	Shy Stock	Re-Pickle	Dents	Burrs	Misc.	Scrap
% Improvement	92.3%	63.9%	52.5%	81.1%	74.7%	56.7%

The worst item was parts rejected due to being short of stock. Rusty stock came second. Note that scrap was reduced 56.7%. This improved quality resulted in a savings of $5,605.48 in scrap and rework over a period of 10 months on the compressor shell.

The corrections in the cases cited were achieved by intelligent analysis and interested cooperation between the operator, production supervision, maintenance, and management. The people who took prompt and effective action were guided in their decisions by the Quality Control Chart. These control charts furnished an accurate, understandable record of the effects of the changes as they were made.

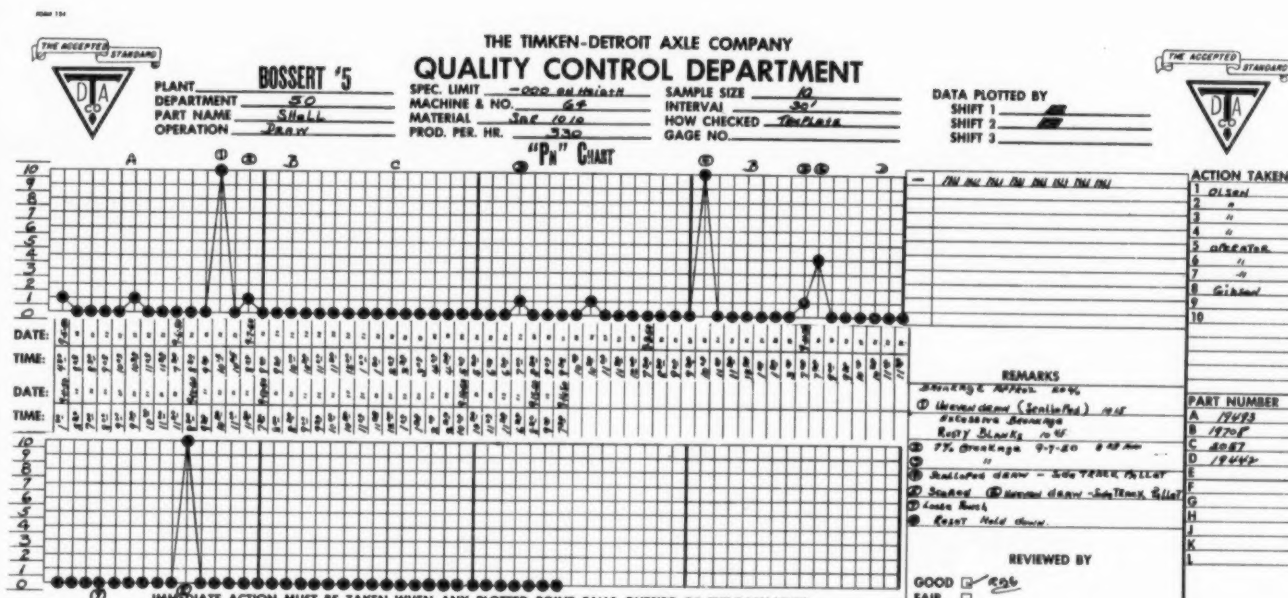

THE TIMKEN-DETROIT AXLE COMPANY
QUALITY CONTROL DEPARTMENT
PLANT BOSSERT '5
DEPARTMENT 50
PART NAME SHELL
OPERATION DRAW
SPEC. LIMIT
MACHINE & NO. 64
MATERIAL SAE 1010
PROD. PER. HR. 330
SAMPLE SIZE 10
INTERVAL 30'
HOW CHECKED TEMPLATE
GAGE NO.
DATA PLOTTED BY
SHIFT 1
SHIFT 2
SHIFT 3
"PN" CHART
DATE:
TIME:
ACTION TAKEN
1 OLSEN
5 OPERATOR
8 GIBSON
REMARKS
Rusty Blanks
PART NUMBER
A 19493
B 19708
C 2087
D 19442
REVIEWED BY
GOOD
FAIR
POOR
IMMEDIATE ACTION MUST BE TAKEN WHEN ANY PLOTTED POINT FALLS OUTSIDE OF THE DASH LINES.

fig 2

THE TIMKEN-DETROIT AXLE COMPANY

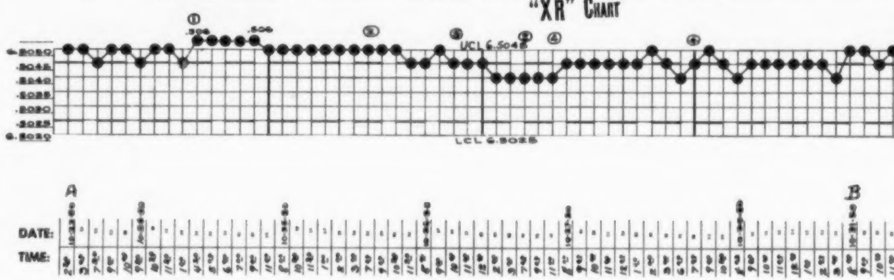
QUALITY CONTROL DEPARTMENT

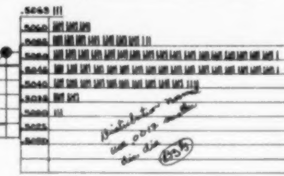
BOSSERT #5

PLANT	BOSSERT #5	SPEC. LIMIT	6.5035 ±.0015	SAMPLE SIZE	5
DEPARTMENT	50	MACHINE & NO.	49	INTERVAL	1 hr.
PART NAME	Shell	MATERIAL	SAE 1010	HOW CHECKED	Dial Bore Indicator
OPERATION	Form	PROD. PER. HR.	330	GAGE NO.	

DATA PLOTTED BY
SHIFT 1 Green
SHIFT 2 Red
SHIFT 3

"XR" CHART





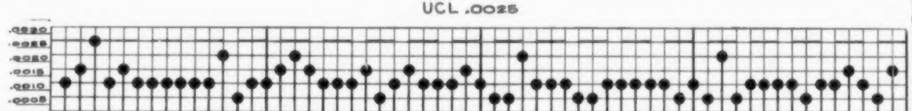
ACTION TAKEN
1 Gibson
2 Operator
3 "
4 "
5
6
7
8
9
10

REMARKS

① ReChecked .5055
② Score Marks - Polish die
③ Shallow Coin - Adjust Press
④ Slug on Punch

PART NUMBER
A 19893-36
B 19442-53
C
D
E
F
G
H
J
K
L

UCL .0025

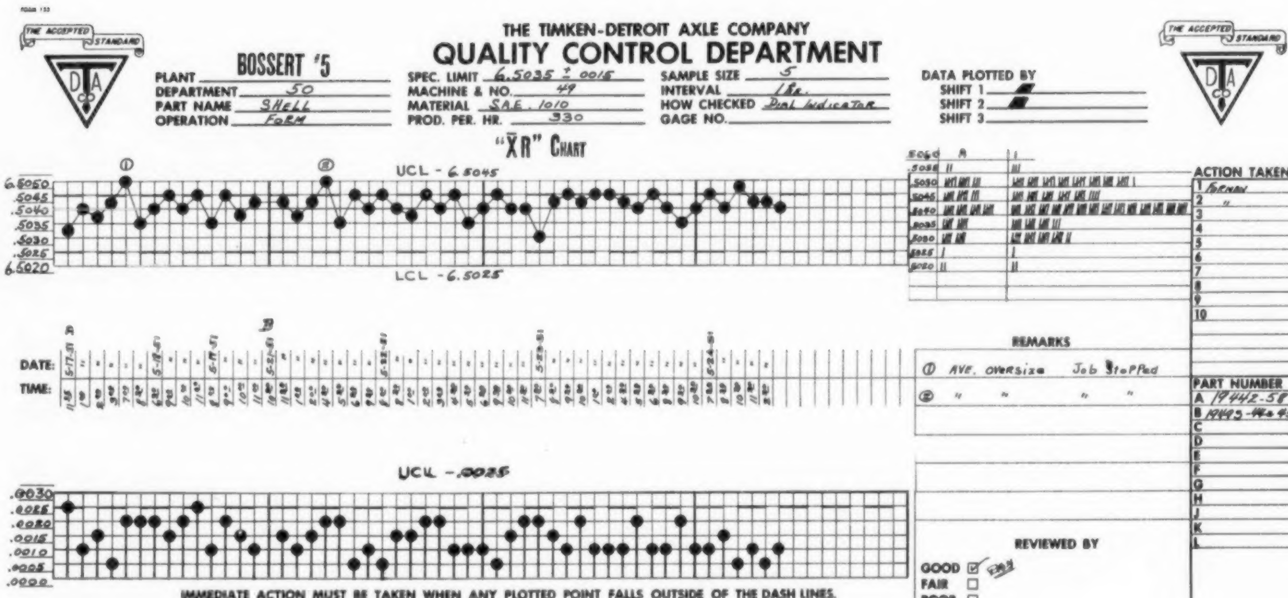


REVIEWED BY

GOOD ☐
FAIR ☐
POOR ☐

IMMEDIATE ACTION MUST BE TAKEN WHEN ANY PLOTTED POINT FALLS OUTSIDE OF THE DASH LINES.

fig 3


THE TIMKEN-DETROIT AXLE COMPANY
QUALITY CONTROL DEPARTMENT
THE ACCEPTED STANDARD
BOSSERT #5
PLANT
DEPARTMENT 50
PART NAME SHELL
OPERATION FORM
SPEC. LIMIT 6.5035 ± .0015
MACHINE & NO. 49
MATERIAL S.A.E. 1010
PROD. PER. HR. 330
SAMPLE SIZE 5
INTERVAL 1 Hr.
HOW CHECKED Dial Indicator
GAGE NO.
DATA PLOTTED BY
SHIFT 1
SHIFT 2
SHIFT 3
"X̄R" CHART
UCL - 6.5045
LCL - 6.5025
6.5050
.5045
.5040
.5035
.5030
.5025
6.5020
DATE:
TIME:
UCL - .0025
.0030
.0025
.0020
.0015
.0010
.0005
.0000
IMMEDIATE ACTION MUST BE TAKEN WHEN ANY PLOTTED POINT FALLS OUTSIDE OF THE DASH LINES.
ACTION TAKEN
1 Forman
2 "
REMARKS
① AVE. OVERSIZE Job Stopped
② " " " "
PART NUMBER
A 19442-58
B 19443-44 & 45
REVIEWED BY
GOOD
FAIR
POOR
Fig 4

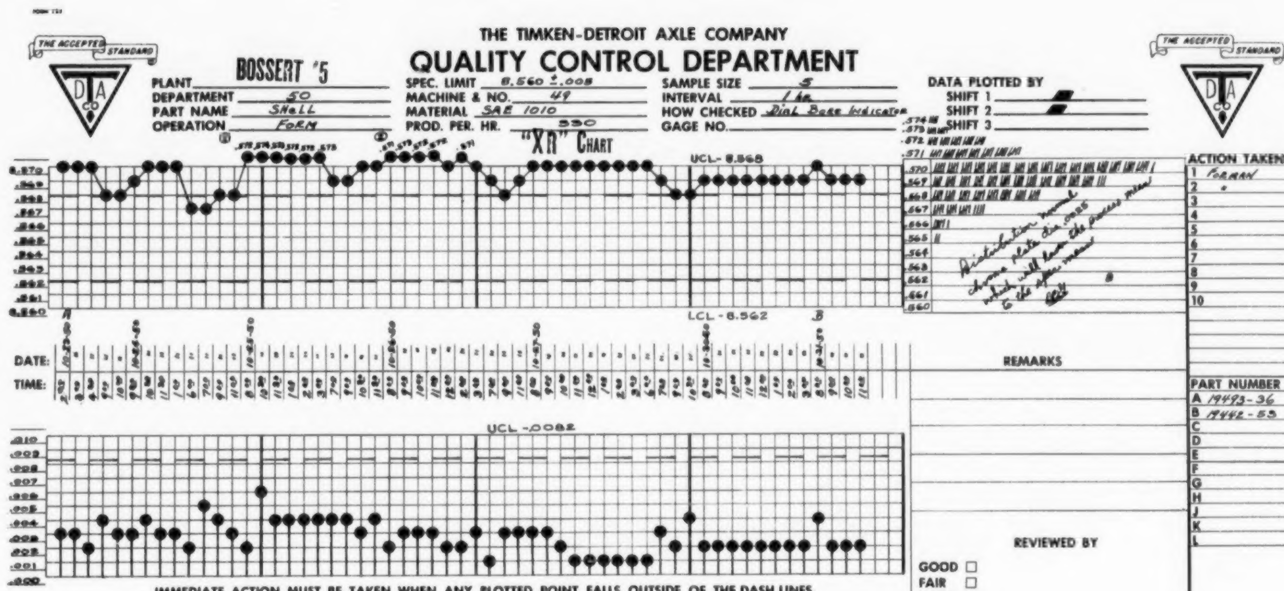

THE TIMKEN-DETROIT AXLE COMPANY
QUALITY CONTROL DEPARTMENT
THE ACCEPTED STANDARD
PLANT BOSSERT #5
DEPARTMENT 50
PART NAME SHELL
OPERATION FORM
SPEC. LIMIT 8.560 ±.008
MACHINE & NO. 49
MATERIAL SAE 1010
PROD. PER. HR. 550
SAMPLE SIZE 5
INTERVAL 1 hr.
HOW CHECKED Dial Bore Indicator
GAGE NO.
DATA PLOTTED BY
SHIFT 1
SHIFT 2
SHIFT 3
"XR" CHART
UCL- 8.568
LCL - 8.562
DATE:
TIME:
UCL -.0082
ACTION TAKEN
1 FORMAN
REMARKS
PART NUMBER
A 19493-36
B 19442-53
REVIEWED BY
GOOD
FAIR
POOR
IMMEDIATE ACTION MUST BE TAKEN WHEN ANY PLOTTED POINT FALLS OUTSIDE OF THE DASH LINES.

fig 5


THE TIMKEN-DETROIT AXLE COMPANY
QUALITY CONTROL DEPARTMENT
PLANT BOSSERT #5
DEPARTMENT 50
PART NAME SHELL
OPERATION FORM
SPEC. LIMIT 5.565 ±.005
MACHINE & NO. 49
MATERIAL SAE 1010
PROD. PER. HR. 330
SAMPLE SIZE 5
INTERVAL 1 hr.
HOW CHECKED Dial Bore Indicator
GAGE NO.
DATA PLOTTED BY
SHIFT 1
SHIFT 2
SHIFT 3
"X̄R" CHART
UCL - 5.568
LCL - 5.562
DATE:
TIME:
UCL .008
ACTION TAKEN
REMARKS
PART NUMBER
A 14495-49
REVIEWED BY
GOOD
FAIR
POOR
IMMEDIATE ACTION MUST BE TAKEN WHEN ANY PLOTTED POINT FALLS OUTSIDE OF THE DASH LINES.
fig 6

"APPLICATIONS OF STATISTICAL QUALITY CONTROL IN A MACHINE SHOP MANUFACTURING TEXTILE MACHINERY"

John T. MacDougall & William G. Cunningham

In September of 1949, Quality Control Supervisors were selected from our own organization; men who knew our product, methods of manufacturing and who were thought well of by our union representatives, to devise a Quality Control program that would be simple and direct so that it would be easily understood by everyone.

These supervisors were sent out to visit several plants in the New England area manufacturing comparable products, to see how these plants were handling their Quality Control programs. At these plants we were counselled to work slowly and after a few applications of Quality Control techniques, the program would accelerate on its own merits.

Our next move was to have a series of discussions with our manufacturing supervisors and union representatives, to explain in detail what we planned to do and to get their support in putting the program over. At these discussions we explained that due to our customers being more quality minded and intensive foreign and domestic competition, it was necessary for us to have better control of the quality of our product. In a simple manner we explained the techniques of Statistical Quality Control we planned to use, plus the benefits each group of our manufacturing team would derive from our program.

It was explained that Statistical Quality Control is a group of tools which our Inspection Department will use to give a better service to our manufacturing departments and help to improve the quality of our product. Also, that by controlling our manufacturing processes, we would reduce the amount of scrap and rework.

We stressed the point that our program would be kept simple and direct as possible, so that it would be easily understood by all members of our organization.

Our program was outlined as having four steps; Machine and Process Capability, Average and Range Charts, Patrol Inspection and Gage Inspection.

We have installed our program in our plant, one department at a time and have maintained the policy of having a meeting with the departmental supervisors and union stewards involved before we move into their department. We feel that these discussions give the various groups an opportunity to ask questions and receive satisfactory answers, thus eliminating misunderstandings and differences of opinion which could lead to grievances later.

We selected our automatic screw machine department for our first application of the program. A few machines were studied for their capability. Average and Range charts were used after the studies proved the machines and processes were capable of manufacturing to the specifications as prescribed by our engineering department.

The program gradually expanded until we had completely covered the department before we moved to another department.

In this paper, we will cover in detail the steps we make installing our Quality Control Program and show some of the results.

We study our machine tools and processes to determine if they are capable of manufacturing our parts to the tolerances as specified on our blueprints. By the results of the studies, we know the amount of variation that a machine or process will produce under normal causes of variation that are inherent to a particular manufacturing process. From these studies, we can determine which causes are responsible for variation beyond the limits of the tolerance.

A Capability Report is issued showing the results of each study. Three copies of a study, which proves a machine and process is capable, are made and distributed to the manufacturing superintendent, departmental foreman and quality control file. This report is made on a white copy of the form. When it is necessary to make a report which proves a machine or process is incapable, four copies of the report are made. The fourth copy is sent to the general foreman of our machine service section. This report is made on a pink copy of the form so it will be easily recognized as a report of an unsatisfactory machine and process.

The departmental foreman is responsible for the follow-up of the pink report and for issuing an internal work order to have the machine repaired. After the corrective measures have been made, a study of the machine's capability is again made.

We have established the following procedures for studying the capability of our machines and processes.

When studying a multi spindle or station machine, we take sub-groups consisting of one piece from each spindle or station each half hour or as the rate of production makes it convenient. Critical dimensions are selected and recorded, consisting of at least one diameter and one length dimension. Not less than five of these sub-groups are taken and somewhere between these sub-groups a sample of not less than four times the number of spindles or stations is taken in manufacturing sequence. The results of the study will not be correct if there is any adjusting of the machine or change in the conditions under which the parts are being

manufactured while the large sample is being taken.

The dimensions recorded from the five or more sub-groups are calculated to determine the average range or barred R ($\bar{R}$) and the machine capability formula $\frac{6}{d_2} \times \bar{R}$ is calculated. The standard deviation and six sigma limits are calculated from the dimensions recorded of the large sample.

The study of single-spindle automatic and hand-operated machines is made by taking at least five sub-groups of five pieces each and also a larger sample of not less than twenty-five pieces.

The two formulas are used in each machine and process capability study and the results of the machine capability formula must be equal to or greater than the results of the standard deviation and six sigma formula before a study is considered satisfactory. If the six sigma value is greater than the results of the machine capability formula, a repeat study must be made.

We have two men taking these studies who have been selected for their knowledge of machine tools and the use of all types of precision measuring equipment, plus their ability to detect errors in gaging, tools, fixtures or methods.

After it has been determined that a machine tool or process is capable of producing parts within the engineering specifications, an average and range chart is placed on the operation. The critical dimension or dimensions are selected for recording on the chart and one chart is used for each dimension selected. A five-piece sample is inspected at least once each hour or oftener as the production cycle so warrants. The control limits we use for average and range are calculated from the tolerance and not from the results of the machine or process.

Our operators and supervisors tell us they like the average and range type of control chart because it keeps them informed at all times during the manufacturing process, as to the relation of the parts being produced to the engineering specification.

We have arbitrarily established our Acceptable Quality Level at two percent. We are using patrol inspection and have established toll gates in the department to maintain the Acceptable Quality Level.

A patrol inspector is assigned a group of from twelve to fifteen machines for which he is responsible. He patrols these machines at least once each hour or oftener as the rate of production requires. He makes out the average and range charts and does the calculating and plotting of the graphs. A table calculated for control lines of average and range is furnished so that knowing the sample size and the tolerance spread he can readily apply the control lines

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A patrol inspector is assigned a group of from twelve to fifteen machines for which he is responsible. He patrols these machines at least once each hour or oftener as the rate of production requires. He makes out the average and range charts and does the calculating and plotting of the graphs. A table calculated for control lines of average and range is furnished so that knowing the sample size and the tolerance spread he can readily apply the control lines

to the chart without any actual calculation on his part.

At each inspection visit to a machine or process, the patrol inspector must inspect a five-piece sample for average and range or a ten-piece sample for percent defective. The critical dimension or dimensions are covered by an Average and Range Chart or Percent Defective Chart. All other dimensions being machined at the operation must also be inspected for visual and dimensional conformance to the blueprint. If the operation is acceptable, the parts produced, since the previous inspection, are taken from the container at the machine and placed in another container, with a blue tag, signifying that the parts have been inspected and accepted by inspection.

Should the inspector find that the parts produced are not within the control lines of the Average and Range Chart, but all pieces are within the tolerance spread, he notifies the operator and supervisor in the area and they are responsible for readjusting the machine, so that the parts will be made within the control lines. These parts are removed from the container, at the machine, and placed in the container with the blue tag.

If the inspector finds that the parts are being made out of tolerance, and over the Acceptable Quality Level that has been established, the inspector places a red tag in the container and notifies the operator and supervisor in the area that the parts, made between his last inspection visit and the time the defective parts were detected, have been rejected and it will be necessary for the operator or supervisor to have the parts screened to eliminate the defective parts. After the lot has been screened, it is submitted to the patrol inspector for a sampling inspection. If the parts are accepted, the red tag is removed and the parts are placed in the container with the blue tag. No parts are to move from any section or out of the department or to future operations, unless there is a blue tag in the container.

In the departments where it is impossible to physically separate the parts made between inspection visits, it will be the quality analyst's and departmental supervision's responsibility to devise some means of keeping the parts separated from one inspection visit to another.

In cases where machines are not covered by either the Average and Range or Percent Defective Charts, the patrol inspector periodically inspects parts being made. If the results of his inspection indicate defective parts are being made, a red tag is placed in the order and the parts are screened by the operator or supervision. These parts are sampled as previously instructed, placing a blue tag in the order after acceptance.

The patrol inspectors record on the back of the route tag any rework or scrap that has been made during the operation or series of operations. When an order has been completed, it must pass through a toll gate where a daily

report is made of each order, recording all scrap or rework as found on the back of the route tag. This report is sent to the Quality Control Office at the end of each day.

From the daily reports received from the toll gates in a department, a Process Average is compiled. A Process Average Chart is located in the department and is posted daily. The average for the previous day is posted each morning, so the employees may know the trend of the quality of their efforts.

A Quality Analyst has been trained to instruct and supervise the patrol inspectors. He may have one or more departments in which he is responsible for the maintenance of patrol inspection schedules and the operation of the toll gates. It is his duty to personally check the settings of all gages in areas under his supervision. He also is capable of taking machine and process capability studies. He must contact the engineering department on all problems of dimension or specification in his area and notify his foreman and the departmental foreman of the results.

A continual inspection of gaging is being performed with the use of a mobile gage inspection unit, outfitted with all the necessary measuring instruments for setting and checking the production and inspection gages.

We are also gradually replacing the old conventional type of plug and snap gages with indicating type gages which actually measures the dimension and informs the operator what his tools and set-up is producing in relation to the specifications.

As a result of our efforts to install a Quality Control Program, the Process Average of the departments has been steadily improving. In the automatic screw machine department the average of rework and scrap previous to our program was slightly over eleven percent. At the end of the first year of our program, the process average for the year was one and two tenths percent and was nine tenths of one percent for the second year. These figures prove definitely a decided improvement as a result of our Quality Control Program.

By presenting our Quality Control methods in a manner easily understood by all and obtaining results, we have created a "quality consciousness" to such an extent we are receiving inquiries from employees and supervisors throughout the plant as to when we expect to place our program in operation in their department.

AF QUALITY CONTROL SPECIFICATION MIL-Q-5923A (USAF) PROVIDES A DEFINITE STANDARD

Walter G. Bain
Brigadier General, USAF

The establishment of the Department of the Air Force in 1947 presented a good opportunity for a re-evulation of Government inspection. Prior to that time, the Air Corps had been a part of the Army, with its own procurement and inspection activities paralleling those of such technical services as the Signal Corps and the Ordnance Corps. The infant U.S. Air Force, however, found its procurement and inspection activities suddenly broadened to include a scope equivalent to that of the Technical Services of the Army or the Purchasing Bureaus of the Navy. Except where "common" items of supply were involved, we were on our own.

During World War II, the Air Corps had experimented with the concept of "surveillance inspection," which at that time was ill-defined and the subject of much criticism from all quarters. The reorganization, coming as it did in a period of relatively low procurement activity, gave the Air Force a chance to study the inspection problem carefully. All approaches led to the inevitable conclusion that some form of surveillance was the only means by which the Air Force could do its job within the limited peace-time budgets and at the same time provide a sound base for emergency expansion. The big task which faced us was defining "surveillance" in operational terms, and providing the organization necessary to put the program into effect. Needless to say, the problem of reorienting the thinking of our own personnel loomed large on the horizon.

As a back drop to the present Air Force Quality Control Requirements, let us review the premises on which our program is based and trace some of the steps in its development.

The unique position of the Government as a consumer dictates the need for Government inspection of all materiel purchased by public funds. The Government has a responsibility not only of assuring the quality of this materiel, but also of treating equitably all of its suppliers. Each citizen has an equal right, in open competition, to do business with the Government. He has a right to have his product impartially judged for conformance to specification requirements. And all citizens have the right to expect that the Government get a fair return for every dollar it spends. It is necessary, then, that the Government inspect or supervise the inspection of all materiel which it purchases. These statements are not mere platitudes and arbitrary positions. They have the force of law, and are spelled out clearly in The Armed Services Procurement Regulations.

Government inspection, then, is a legal requirement which protects the citizen both as a tax payer and as a competitor for Government business. It is intended to guarantee that military supplies conform to contractual requirements and that in both quality and quantity the Government gets what it pays for. Planning and organizing to fulfil these responsibilities in the best way possible was one of the tasks which faced the U.S. Air Force.

One of the first steps was the separation of inspection from the procurement function and the establishment of the Inspection Division at Hq AMC in

1948. A short time later, the Division was redesignated the Quality Control Division, in view of the fact that the functions of this organization transcended the field of mere inspection. This new name did not imply that the Air Force intended to control quality in the usual sense. Rather, it recognized that any kind of "surveillance inspection" would be ineffective unless the contractor properly controlled his own quality.

At about the same time, the Air Force recognized the need for greater utilization of statistical techniques in the field of quality control and assigned a Statistical Quality Control officer to the Division. Since then, Statistical Quality Control has been an area of ever increasing interest and activity.

In 1949 the Stanford Research Institute prepared under contract a comprehensive review of the inspection function of the Air Force during World War II and proposed many recommendations for its improvement. The study augmented the Air Force's own studies and helped to accelerate the reorientation of the Air Force point of view.

During the genesis of the AF Quality Control program, such authorities as Grant, Olds, Juran, Burr, and Littauer made valuable contributions to our planning. Three of these men are presently retained as consultants to the Air Force on quality control problems.

Before launching into the details of Air Force Quality Control Requirements, it might be well to review the basic criticism directed against military inspection during the last War. To keep the ledger balanced, we might equally well consider some criticisms directed at industry by the Armed Services. In general, industry protested against:

a. Too much duplication among the services.

b. Too much duplication of the contractors' efforts.

c. Military inspectors, especially civil service personnel, were poorly trained and unqualified for their job.

d. Many of the design specifications were too rigid or too ambiguous.

e. Many of the design requirements were impractical, too complicated, and did not follow standard commercial practices.

f. Too much 100% inspection--too little checking and use of statistical quality--control methods.

g. Not enough cooperation and awareness that the contractor could do the job, if given the chance.

h. Too much RED TAPE.

The Armed Services decried:

a. Lack of knowledge of the contract and its requirements.

b. Deliberate efforts on the part of some contractors to evade the contract requirements or make good a low bid by "cutting corners".

c. Lack of any inspection system that could be called one, especially true of small and medium-sized concerns.

d. An attitude, on the part of some, of "soak the Government wherever possible".

e. Limited use by manufacturers, particularly small and medium-sized companies, of modern management techniques and statistical quality control.

f. An unsympathetic attitude toward use or introduction of quality--control techniques--sampling, control charts, etc.

g. Lack or inadequacy of quality history records by many companies.

h. An uncooperative attitude.

These criticisms were summarized by the National Industrial Conferences Board in a 1951 Business Policy Study. It should be pointed out that they do not all apply to any one industry nor to any one of the Military Services. They represent a cross-section and a summary of opinions. However, it will assist in understanding some of the aspects of the Air Force Quality Control program if these criticisms and shortcomings are kept in mind.

The cornerstone of our Quality Control program is the Air Force Quality Control policy, which I ask you to consider carefully.

"CONFORMANCE": Conformance to contractual requirements of supplies presented to the Air Force shall be determined on the basis of objective quality evidence. Such evidence will be obtained by the contractor and will be evaluated and verified by the Air Force Quality Control Representative exercising surveillance over the contractor's facility. Evidence may also be obtained independently by Air Force Quality Control personnel.

"PRODUCT INSPECTION":

a. Product inspection by Air Force Quality Control personnel will be used to the extent necessary to verify evidence of quality submitted by the contractor or it may be used to determine acceptability of supplies on an individual or lot basis.

b. The amount of evidence obtained or verified through product inspection by the Air Force Quality Control personnel will depend upon the nature and intended use of the product and the effectiveness of the contractor's control over quality.

Operationally, Air Force Quality Control starts with the contract. Most Government contracts contain a standard or "boiler plate" clause which in essence requires that the contractor establish and maintain an inspection system which is acceptable to the Government. Because, as reflected in the above policy, acceptance of supplies is based largely on objective quality evidence furnished by the contractor, this evidence must logically encompass all functions which affect quality. Hence, the Air Force thinks and speaks in terms of quality control systems rather than inspection systems. Obviously, the statement "acceptable to the Government" is not at all definitive. Unless guide lines are provided, the question of acceptability is a matter of opinion on the part of the Government inspector rather than a matter of fact. Such guide lines were provided by the Air Force in December 1950 by the

issuance of Specification MIL-Q-5923, which was superseded in September 1951 by Specification MIL-Q-5923A. The enforcement of this specification is the job of the Air Force Quality Control inspector who maintains surveillance over the contractor's quality control system. Reduced to its simplest terms, this surveillance consists of the evaluation and verification of objective quality evidence furnished by the contractor.

Specification MIL-Q-5923A sets forth the Air Force's minimum requirements for an acceptable Quality Control or inspection system. It states the requirements in general terms, by giving the "what" while leaving the "how" up to the discretion of the contractor, with the approval of local Air Force Quality Control personnel. Thus it is sufficiently flexible that it is suitable for all sizes and types of manufacturing organizations and for a wide range of supplies procured by the Air Force. At present, it is an uncoordinated MIL specification. It is hoped that at some future date it may be adopted in substance by the other military services.

The specification is applicable in whole or in substantial part to many of the types of supplies procured by the Air Force. Dollar-wise, it is applicable to a very large percentage of Air Force procurements. The types of supply procurements to which the specification is not normally applicable can best be summed up by the term "commercial type articles." For such articles, ordered primarily in accordance with commercial specifications or vendor's catalogues, the existing quality control system is usually considered satisfactory if it will assure the maintenance of commercial quality standards.

I shall now outline the main provisions of MIL-Q-5923A, giving particular emphasis to certain topics which I felt might be of especial interest to this group. The first requirement is that the contractor establish and maintain an efficient and economical Quality Control or inspection system. It is the basic responsibility of the contractor to provide sufficient inspection coverage, from the receipt of raw material to the packing and shipping of the end item, to assure that the supplies meet all contractual requirements. Contractors are required to submit evidence of such conformance prior to submission of the supplies to the Government for acceptance.

The contractor is obligated to prepare a Quality Control Manual which will spell out the general procedures by which he intends to comply with the requirements of the specification. Such a manual should include an organizational chart and a functional plant diagram showing inspection stations. It should include exhibits of inspection operation sheets, forms, and records used in inspection, and a general discussion of their use. Detailed inspection and test procedures need not be included as an integral part of the manual. Air Force approval of the manual must normally be obtained prior to the completion of the first production article.

The contractor's Quality Control system is subject to periodic rating surveys by the Air Force. A survey results in either an approved or disapproved rating, or the rating may be deferred until action has been taken to correct the discrepancies noted. A disapproved rating indicates failure of the contractor to provide an acceptable system as required by the terms of the contract.

The section on raw materials sets forth those circumstances in which test reports are required and makes provisions for the use of certificates in certain cases. There is also a requirement that the contractor provide

facilities for withholding raw materials from issue pending verification of the type of material.

Subsequent sections set forth, in general terms, the contractor's responsibility for providing suitable inspection facilities and equipment. The contractor is required to provide such inspection measuring and testing equipment as is necessary to determine conformance of the supplies to contractual requirements. It is also required that the contractor periodically check such equipment at established intervals. Production tooling used for inspection must also be checked at frequencies determined by the type and use of the tooling. The schedule prepared by the contractor and approved by the Air Force becomes a part of the Quality Control procedure and should be incorporated in the Quality Control Manual.

The contractor is required to provide procedures to assure that the latest applicable drawings, technical order requirements, and contract change information are available at the time and place of inspection. All engineering changes must be processed in a manner which will assure accomplishment on the effected article at the specified effective point. Records must be maintained of such changes as they are made and must be readily accessible to contractor and Air Force inspectors. Provisions must also be made for the removal of obsolete engineering information from points of issue and use concurrent with effectivity of the change.

The Air Force does not require any contractor to establish a formal statistical quality control system. It does require, however, that any sampling procedure used by the contractor be subject to the approval of the Air Force inspector. MIL-STD-105A is preferred for attribute sampling, since it is used by all military services and makes for much easier administration by the Air Force. It is not necessarily considered inherently better than other sampling tables, which may be used with the approval of the Air Force inspector. As a general rule, Classifications of Defects and AQL's are proposed by the contractor, subject to Air Force approval. Approved Statistical Process Controls may be used to reduce inspection requirements, but may not be used to eliminate final inspection. When such controls are used for acceptance purposes, they are subject to approval of the Air Force. This is not true of process controls used entirely for manufacturing control purposes, such as for checks on tool wear.

Since the furnishing of objective quality evidence by the contractor plays such an important role in the Air Force program, it is essential that adequate instructions be issued to contractor's inspectors and that records be kept of inspections and tests performed. Inspection instructions must list or reference all physical and dimensional properties which would affect safety or result in material reduction of usability. Obviously, when sampling inspection is used, sample sizes and acceptance or rejection criteria are required. If formal C/D's are used, they must also be included in inspection instructions. Records must be kept to show that required inspections have been performed and must indicate the results. Such records must in some way reflect the recurrence of discrepancies. These records are evaluated by the Air Force inspector to determine that they provide the amount and kind of evidence necessary to make a decision of acceptability, and to check for computational accuracy. They are verified for correctness by actual physical inspection on a predetermined basis.

The section on special processes calls attention to the fact that certain Government specifications require the approval and/or certification of

processes such as welding, x-ray, magnetic inspection, heat treating, plating and oxidizing, including the equipment and operating personnel. MIL-Q-5923A of itself does not require certifications unless they are called out in the contract by the applicable process specifications. Air Force policy is in the direction of placing major responsibility for certification upon prime contractors, under the surveillance of the Air Force.

Considerable space in the specification is devoted to the Materials Review Procedure, which, incidentally, is a joint procedure used by both the Air Force and the Navy Bureau of Aeronautics. Before discussing Materials Review, however, it would be well to look briefly at some related matters not covered in MIL-Q-5923A.

The term "Variations" is used to describe departures from specified requirements which do not adversely affect safety, performance, weight, durability, or interchangeability. Any departure which might possibly affect any of these factors is known as a "Deviation." No article containing a Deviation may be accepted without engineering approval of the Wright Air Development Center (formerly Engineering Division, Hq AMC) and the issuance of contractual authority for acceptance. Discrepancies in an article which are clearly Variations, may in certain cases be accepted by the Air Force inspector through materials review procedures. Such acceptance does not constitute engineering approval, which is the responsibility of the contractor. Minor design changes may also be accepted by the Air Force inspector, but he is not authorized to approve or sign such changes. In borderline cases where there is a question as to whether a departure is a Deviation or a Variation, such a decision is in itself of an engineering nature and will be referred to engineering authority by the Air Force inspector.

Since Materials Review is a well known joint procedure used by the Bureau of Aeronautics and the Air Force, I shall not dwell at length on the subject. I do want to emphasize that Materials Review is not primarily a salvage procedure nor a means of preventing production bottlenecks, although in actual practice it does result in a saving of critical resources. Materials Review is intended to obtain corrective action on the part of the contractor to remove the cause of the discrepant material. Recurring discrepancies on which inadequate corrective action has been taken will not be accepted as a matter of routine by Materials Review Boards. In any case, only Variations may be accepted through Materials Review procedures.

It is desirable to include Specification MIL-Q-5923A in whole or in part in certain subcontracts and purchase orders where Air Force source inspection is required. Source inspection is in effect the extension of the activities of the Government inspector at the prime plant. Surveillance by the Air Force inspector is facilitated by the subcontractor having an acceptable quality control system which will furnish the necessary objective quality evidence. Naturally, the specification is not applicable to subcontracts or purchase orders for items, such as commercial-type items, which are excluded when considering prime contracts.

I should like to emphasize that source inspection is performed entirely for the benefit of the Government inspector at the prime contractor's plant. It does not relieve the prime contractor of his responsibility for furnishing the Government a completely acceptable end article and does not guarantee final acceptance of any of the source-inspected material. The Air Force normally limits source inspection to articles with important interval

characteristics which could be examined only by a major disassembly or by methods which might involve damage to the item. In certain cases, source inspection may be performed where specialized or complex equipment required for proper inspection or test is not economically available at the receiving contractor's plant.

Requirements for the design and use of inspection stamps, as discussed in MIL-Q-5923A reflect the Air Force policy of minimizing the use of Government stamps. Except for a few cases where commodity specifications require the use of the AN stamp, contractor's approval stamps are recognized as Air Force equivalents.

With this summary of Air Force Quality Control Requirements in mind, let us look briefly at the Air Force organization for Quality Control and explore our concept of surveillance.

The Quality Control Division at Hq AMC establishes quality control policy and general procedures for the Air Force and monitors all Air Force quality control activities. We have a counterpart organization on the staff of the Commander of each of the six Air Procurement Districts. Similarly, each Region within a district has a quality control section. Certain large facilities have an AF plant representative, reporting directly to the District Chief. The plant representatives have their own quality control sections. Inspection responsibility for each Air Force supply contract is normally assigned to a specific Air Force Quality Control Representative. Depending on the size of the contract and other workload factors, he may be assisted by a large staff of inspectors, or he may cover a number of facilities on an itinerant basis. In any case, all Air Force quality control inspectors are responsible; through channels to Hq AMC, they are guided by a single Quality Control Policy in the enforcement of a definite quality control standard.

Now consider, if you will, a typical plant with a Government contract. The Government inspector is responsible for determining that the materiel furnished by the contractor complies with all the contractual requirements before he accepts it for the Government. If we happen to be speaking of an Air Force plant, we say that our inspector maintains surveillance over the contractor's quality control system. Just what does "surveillance" mean? Some critics of the concept call it "strolling and looking." Actually, we intend that it be a carefully planned program, designed to:

a. Assure that the contractor has an acceptable quality control system as required by the terms of the contract, and

b. Assure that the articles presented for acceptance conform fully with contract requirements.

The Air Force inspector is required to have an up-to-date, written plan of operation. It must show in detail how he checks each part of the contractor's system for compliance with MIL-Q-5923A. It must provide the detailed methods by which he will evaluate and verify objective quality evidence furnished by the contractor. The plan should include predetermined schedules for actual physical inspection used in verification. This verification inspection is by no means a haphazard "spot check" at one

extreme nor a duplication of the contractor's efforts at the other. It is intended to be a measure of the contractor's inspection efficiency. Let me illustrate with an actual case from a large plant manufacturing complex assemblies. Periodically, an assembly already inspected by the contractor is selected at random by the Air Force inspector and completely reinspected. Suppose the contractor's inspection disclosed 40 "squawks" and the Air Force picked up 10 more. This would indicate that the contractor's inspection was only 80% efficient. A running "efficiency index" is used as a basis for making recommendations to the contractor and for adjusting the extent and frequency of verification inspections by Air Force personnel. The Air Force inspector is required to keep records of verification inspections which he has made in order to substantiate his acceptance of the contractor's material.

From my previous remarks, you may feel that I have been stressing PLANS AND RECORDS. I hope that is your reaction. Good plans and records are, we feel, the fundamental requirements of an effective surveillance program. The contractor must plan his quality control system. This plan should be reflected in his manual, which provides the basis against which the Air Force inspector checks the actual system. Records are the medium by which objective quality evidence is presented to the Air Force inspector for his analysis. Likewise, the Air Force inspector must thoroughly plan his surveillance activities and must support them with adequate records.

I have discussed in general terms the Air Force Quality Control requirements, and have touched briefly on the methods by which the Air Force assures compliance with them. There are two key thoughts which I would like you to take back to your plants:

First, MIL-Q-5923A is not a compendium of inflexible bureaucractic rules. It is a clear, workable explanation of the "boiler plate" inspection clause of the contract, and is adaptable to a wide range of conditions. For the first time in the history of military procurement, every Air Force bidder can now know just what will be required of him in the way of an acceptable quality control (or inspection) system.

Second, Air Force surveillance over the contractor's quality control system is not a haphazard "strolling and looking" affair. It is designed to be a carefully planned program whereby the Air Force fulfils its legal responsibilities for quality assurance in the most efficient and economical way possible.

We of the Air Force are proud of our pioneering efforts along these two lines. We feel that they represent a great step towards the Munitions Board goal of uniform inspection and quality control practices in the Department of Defense.

THE HUMAN FACTOR IN QUALITY CONTROL

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The Introduction of Quality Control in a plant or a business usually stems from a meeting attended by management people. Frequently the first work centers around demonstrations of distributions and the development of charts. After this first flush of enthusiasm takes place the problems become much more difficult. Problems begin to involve a number of other things. For instance, how does this new Quality Control fit into Inspection? How does it fit into the Engineering and the Production Departments. Is Quality Control an advisory service or is it an operating service? What now are we going to do with this thing that we have developed? It is at this point that I believe that we can very well look at the impact that Quality Control makes upon the people that are going to be involved in its use.

What is the impact that Quality Control makes on the people that it touches? In the first place it seems to me that we could stop for a moment to stop and look at the Qualities that make a human being what he is. For the purposes of this discussion we can look upon the personality of each man as having three inter-related characteristics. The first is that a human personality is made up of intelligence and I do not mean intelligence in the sense that we test it with examination, but I mean intelligence as a factor in reality that enables us to predict on the basis of our experience. Intelligence is the functioning ability of the human being to grasp or respond to reality. In other words a person is effective in his intelligence if he can understandingly encompass reality and exercise some control over it. If he can predict, he is intelligent. So the first aspect of human personality is something that is easy for people in Statistical Quality Control to appreciate. It is the ability to comprehend and respond to and to grasp reality and to be able to predict.

The second aspect of our personality that is involved in our dealings with the world around us. We feel in response to everything. There is no stimulus that can touch us that does not in some way give us a feeling tone. We feel in response to everything that touches us. We feel in response to things that are said to us. We feel either pain or we feel pleasure. We feel good, or we feel bad. We feel exhilarated, or we feel depressed. We respond with feelings to every single thing that happens around us. There are many things that are so small that we don't respond very strongly. Our response pattern is usually small in response to a small stimulus. But no matter how small the stimulus, there is a response in feeling. Many of you are in engineering and when you talk about .0001 in some quantity or other, you are talking about a small amount. And yet a stimulus as small as that will produce response. The response, it is true, will generally also be in the order of .0001 but the important thing is that there will be a feeling response to everything that happens to us.

The third factor that makes up our personality is our fantasy life. This is the way in which things happen as we would like them to occur. The intelligence allows us to see reality, the feelings allow us to have some control, and the fantasy gives us our aspirations and our motivations. Many men feel that the mark of a mature person is that he has no fantasy life. Many people are very proud of being extremely literal. Many engineers have been trained that they want to be able to touch a

thing and to measure it and to feel it. To such people if it has not quantification, it is not any good. But nevertheless, our whole life experience shows us that there is something in us that gives us aspirations or goals that are beyond quantification and this is the fantasy life. This fantasy life or the imaginative life is the life in which we are in a sense Walter Mitty, great inventory, or Walter Mitty, great explorer. It is true that if carried too far, that fantasy life becomes similar to that of children or mentally disturbed people. It is understandable that a large number of people suspect that fantasy life is not wholesome. There is no doubt that if it is carried too far we have actual evidence of immaturity. However, even an elementary analysis of our personality will lead all of us to appreciate that our fantasy life or, seeing things as we would like to have them be, becomes a very important aspect of our personality. It is the thing that enables us to take a little criticism and go out and either turn it for our own use or say, "Well I wish I had told him what I really think." It is in fantasy that we become so effective--that is, after the meeting is over. Now these three factors of intelligence, emotions, and fantasy are critical for our understanding of what I am trying to say.

Our personality includes the three sides of this triangle. The intelligence, or the ability to grasp reality, the feeling of response or our ability to control ourselves, and the fantasy life which gives us our motivations, our aspirations, and our goals. But none of them can be taken separately. Many people feel that they can be intelligent now, emotional then, and live in fantasy afterwards. The three things cannot be separated. It is futile for anyone to believe that he can go into a group, or work with a group on the basis of pure intelligence. If I try to sell Quality Control, or anything else to a group on the basis of pure intellectual appreciation, I am almost certain to fail. I must take into account the complex nature of the personalities with which I deal. Now what does this mean in terms of Quality Control? It means that Quality Control must sit down with itself and decide that sooner or later it is going into industry, business and manufacturing through the back door, through the roundabout way of ekeing its way into inspection and engineering, or it is going to go through the front door and be a profession. I think that all the signs show that Statistical Quality Control or Quality Control taken as a profession, has decided to become a profession and to go through the front door of industry rather than through the back door. It appears to me that the signs of the forthcoming profession in Quality Control are already with us. You know in my field we believe that a profession has certain marks. If it does not have these marks it probably is not a profession - it is a trade. The marks of a profession that seem to apply to Quality Control today, seem to be these: First, it has a body of organized knowledge that is intellectually communicable. A trade is generally marked by the development of skill by doing the job over and over again. A profession is marked by the intellectual communicability of the subject matter. Statistical Quality Control seems to me to have the first mark of a profession.

The second mark of the profession which it seems to have to date is that there is a great responsibility placed upon the individual operator. When a person is operating in the field of Statistical Quality Control, the very nature of the operation makes it difficult for a lot of people to check him and to make certain that his work is right. A great deal of personal responsibility therefore rests upon the practitioner in the field of Quality Control. In the third place there seems to be an altruism in the profession. All professions must have some altruism. It is to be regretted that our modern economic life seems to put more and more pressure

upon the professions. Sometimes there seems to be little altruism in them. However, a true profession deals with work that must be done because mankind has a need that must be met. Thus the greatness of the great professions of the past, of theology, of medicine, of law, all gained their greatest fame when altruism was at its peak. Now since we must all earn a living, I am not going to belabor this point of altruism. We live in a world in which a man must earn his living, but there is, I believe, in all of the people that I have met in the field of Quality Control a willingness to go beyond the limits of their ordinary jobs in order to help people understand Quality Control, so I am satisfied that there is this characteristic of altruism. Now if these characteristics are true, then I think we can assume that Quality Control is likely to go in the front door of business as a ranking profession in its own right. If that is true, then other problems develop. We can say that there are two different sets of problems that come to Quality Control if it is going to become a profession. Both relate to people.

The first group are those of relationships of plant with management, with Quality Control people themselves, and with the production departments of a company. Now in regard to management, it seems perfectly obvious that techniques have to be developed for adequately selling Quality Control. It is a human factor, a human element, a purely psychological matter; because if what I have said is true, it is absolutely impossible to do a competent selling job of Quality Control or any other branch of knowledge on a basis of pure intellectual activity alone. We will not accept things merely because our minds give assent. I believe there have been times when the effort has been made to try to sell management on an intellectual basis alone. The second part of this relationship with other people has to do with the problems within the field of Quality Control itself. There is no question that in such a group as this, there will be tremendous problems of personal understanding of each other. It is a new field and therefore it has drawn large groups of people from many different branches of learning and activity. There will be a percentage of engineers. There will be a number of statisticians. There will be a number of people who come from production control. There will be some people who come out of cost accounting. There will be people who come from every branch of human activity that relates to the running of a business. Because these people are from the backgrounds that they are, they are going to see things in the light of their experiences. They are, in other words, going to interpret in the light of the things that they have known so that the differences of opinion that would be expressed in a meeting of this kind on any technical issue will probably be very great. A great mathematician and a great statistician will be interested in developing further theory. On the other hand, a man who comes into this field out of production will be so interested in getting some quick utility out of it that he may feel very strongly that the less emphasis placed upon any mathematics on the problem, the better. He would like to develop a technique in which theory does not make its appearance at all. In between those two extremes there will be all manner of people who have to learn to get along together. Is it not obvious with this background in the members or the diverse background of the people who are in Quality Control that it behooves the members to be exceedingly conscious of the needs and feelings of the rest of the group, so that they do not press their views beyond what is reasonable? I am particularly concerned that the Quality Control people try to develop in themselves a breath of understanding of the needs of the people with whom they deal so that they are conscious of the fact that even with one another they cannot expect agreement and they cannot expect just to give intellectual advice to the group in the shop and in the factories. Many have had excellent results but so far the results seem to be successful in spite of the personality of the Quality Control Engineer who is trying to do the job, and in spite

of the relationship that he has with the superintendent, the manager, or whoever else he is dealing with in the shop. It is a personal matter thus far and a technique has not yet been developed that is foolproof. Let me illustrate this with a reference to a great institution in Chicago. Many years ago Hull House was started by Jane Addams. It is still a very great social welfare institution in Chicago, but no one has ever yet been able to reach the stature of Jane Addams. Jane Addams and Hull House were almost synonomous in American life and in particular in Chicago life. Hull House was the product of a great idea of a great woman. Unfortunately, no one has been able to develop a technique that will ensure continuing greatness in a settlement house. No one has been able to formulate a technique that can be guaranteed to make Quality Control great, but because it does have the characteristics of a profession, it appears to me that there will be the development of the necessary techniques. I don't believe that Quality Control is destined to remain a parallel to Jane Addams and Hull House. I believe that it is more likely to be analogous to the development of Medicine. Today we can go to any physician, and while we know that he may have certain shortcomings in one field or another, he at least has a reasonable and fundamental ability to deal with the situation that we bring to him. We believe that there is an analogy that can be drawn from a profession such as Medicine rather than that the analogy must always follow that of the great person idea, taking Jane Addams as an example.

Now, in dealing with people, whether in management or in one's own group or in production, it seems to me essential that we have some further understanding of what causes people to act and think the way they do. I have already discussed what seems to make us up as a personality. How do we act? I think the first thing that is essential for quality people to keep in mind is that there is a constant unwavering and unremitting tendency on every human being's part to project. Projection simply means that man tends to see, to hear, to feel, to taste, and smell what he needs to feel, to hear, to taste and to smell. We project our own needs out into life and I see you as I need to see you and you see me as you need to see me. Of course it is perfectly true that the normal person ties this projection into a reasonable adjustment with reality. But, in general, I see you as I need to see you. I can see you as a pleasant person if I need to see a pleasant person out in front of me or I can see an unpleasant person. We constantly project, as a matter of fact it has been discovered that we project our needs so out into the outer world that a whole system of psychology has been developed around the idea that if we can get a person to express his needs through projection of himself we will get a picture of his personality. Now, without belaboring the psychology of this point, I want to say that the fact that every human being projects must sooner or later be taken into account if this profession is to reach the heights that you want it to reach. The president or the vice president of a company must be sold on the basis of his needs - not your needs. Some will try to sell Quality Control on the basis of their needs because they project their needs. This tendency toward projection of our own needs can only be avoided by developing insight, or self understanding. Insight into one's self and insight into the other person are the only safeguards that I know that are worth anything against this constant tendency that we have to project. He who does not have to project hostility tends to be a relaxed person. He is also quite non-defensive. He does not have to argue. When someone says to him, "I think Quality Control is without merit," he doesn't have to say, "Well, I would like to tell you that it has saved us $400,000 in our plant in the last year." The non-defensive, well adjusted practitioner in the profession of Quality Control would be more likely to say, "It is interesting that you say this field is without merit. That interests me. Would you tell me why you feel that way?" Because he is non-defensive about it, he is relaxed to the point where he does not have

to fight it any more.

I would like to emphasize that if Quality Control is to be sold on the level of top management or to the worker or anywhere in between, it is essential that we understand the constant tendency that we have to project our own feelings, shortcomings, anxieties, fears, and instead get enough insight to be able to go at this in a relaxed way. Another thing that would have to be kept in mind if we were to sell Quality Control is that in a new field the people involved in it are very easily frustrated, become very touchy on the subject because it seems that there is so much to do and so little time in which to do it. Therefore it is only natural that a man can expect in his own department, if he is in the field of Quality Control, that there will be times he will begin to doubt himself because he feels frustrated and he must get ready for these feelings. Furthermore, I think we must appreciate the tendency all of us have to resist change. Change is difficult because we all like to develop habits and the moment we have to change anything, there is a natural tendency to resist the change because it does not seem as if the new thing is worthwhile. It seems to me that it is not remarkable at all that you have an old superintendent in your plant who says, "I doubt the validity of this whole thing," or "I think the whole thing is no good." There is nothing at all remarkable about that because it is a perfectly natural tendency to resist change. Now that brings up what I consider a very important aspect of this matter and that is that I suspect that since we do project, since we are easily frustrated, since we do resist change, you might just as well get ready to bring more people at least into the fringe of Quality Control. If these things are true about people, we are not ever going to be able to cram a goal of any kind down their throats. A number of industrial psychologists have made studies of productivity of workers under various controlled circumstances, where the superintendent fixed the normal output, where a time study fixed the normal output, where a production department fixed the normal output, where the production department fixed the timing of a line, where a psychologist had talks with the people and helped them determine a goal for themselves, and where the workers with their foremen decided upon a goal by themselves. It was found that the only motivation that produced a significant difference over the average of all the rest was the motivation that came when a small group of workers doing the actual work themselves fixed their own goal. As far as the evidence is now available there seems to be no way in which we can impose a goal upon another that is in any way significant as far as producing faster or better. The only useful thing comes when a man sets, or people set their own goals. There are examples of this in any plant. You have seen the second shift decide to show how much better it was than the first shift. This applies at all levels. The whole process can only be taken along as fast as the people can take it and set their own goals and any effort to push them further is going to result in increased frustration on the part of the Quality Control people. I think a great deal more time should be spent in the formulation of goals before an effort is made to approach those goals. What are the goals and why should they be reached? When they are reached on the executive office floor of a company's office building and then translated a week later down through somebody named Joe into a small press operation, don't think that you are going to get very far. I know of a foundry that attempts to maintain a Statistical Quality Control chart on cupola temperatures. It is a gray iron foundry and at the moment the only person who is interested in it is the manager. The metallurgist and the men have no interest in it and the chart has all of the variations you would expect from an uncontrolled operation. Yet, the manager keeps a chart there hoping that one of them will become curious enough to look at it some day and wonder if something couldn't be done about the variations.

But as long as there is no goal here that is accepted by the individuals that are involved in it, it is going to be an uncontrolled operation. People are not all alike and so often we insist that we treat them as if they were alike. Many supervisors will not take into consideration the individual differences among people. Of course, we do take these differences into account when we say that John is not competent for a job, but we often deny the same differences in personality. I have heard men say "Business is no place for playing favorites and any variation in your treatment is favoritism." This remark is nonsensical. Each person is different. He is a different complex of feelings and of fantasy. Because he is different he is going to have to be handled differently. In other words, we are going to use one technique to sell this to the President and another technique to sell it to the Executive Vice President and perhaps still a third technique to sell it to an Engineering Department. There may be five or six levels at which this program must be adopted and believed in. There may be five or six methods by which it is possible to have these people understand the subject matter and the scope of Quality Control. If Quality Control is to be successful, the mathematics of it and the statistics of it are going to be one of the smallest things in it. They are essential, certainly. They are essential in the same way that a knowledge of anatomy is essential for surgery. But if it is going to be a true profession, it is going to be an art rather than a science. When the physician deals with us he is acting as an artist. The physician is as true an artist as is a man who paints a picture. What is he doing? He is taking all the sciences that comprise medicine and he brings them together in a great gestalt. Similarly in Quality Control, it is not a science. It is a group of sciences and its application is an art. The profession of Quality Control is going to be an art and is going to be based upon a number of sciences. It is based upon the science of mathematics and all of the correlary sciences. It is going to be based upon a science of measurement, but when the whole thing is wrapped up it is going to contain its psychological and sociological aspects. It is going to be an art that is based upon a dozen different sciences. The goal that is ahead of a profession that looks at itself in this professional light is a very great goal because of the good that can be accomplished both to the individual and to the companies that make use of it. I have seen so many men at one Quality Control meeting or another who see the implications of this instrumentality if it can be put to work. You can see what it would mean to a business; you see that it could be the next great revolution in business; it could be a revolution as great as a punch press or an assembly line or interchangeability. I have seen in many of you the feeling that there is a tremendous force here if it can be properly developed. The system of Quality Control applies to even the work of the president. If he ever sees the point of what this means he can apply it to his own office. It is not only in the factory, it is also in the office. Some have seen the possibilities in Quality Control. There is a possible application to the development of every single human being. The concepts that underlie Quality Control are applicable for our own personal use of them. We can manage our own affairs under a program of Quality Control. There is so much in life that will respond to Quality Control that the path of growth has had only a few steps taken along the route. I feel strongly about this since the field of psychology has certain similarities with your field. We know now quite a bit but what we know now is almost infinitesimal with what we don't know. We have gotten to the point where we can do well in describing the personality of a man. We can tell reasonably well what he is like and yet we still haven't developed very good techniques for making him better. Similarly you have considerable skills. You are very good at putting your finger on the difficulty. You are not quite as good as you would like to be in doing something about fixing the difficulty.

I think that your field will require two parallel developments. One line will be the development of technical knowledge. The other line will be the development of the personal skills and the art skills to make the profession function with effectiveness. I believe that the more time that is given to the development of this personal factor, the more success you are going to have.

PROBABILITY STATISTICS APPLIED TO THE CONTROL OF TAX-RETURN OPERATIONS

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One of the major sciences that can be applied to solve quality control problems is probability statistics. Whether we are using sampling inspection, or statistical quality control, or design of experiments, or analysis of variance, or correlation analysis — we are applying the principles of probability statistics. It is no accident that this science is so closely identified with quality control. This is because it is a methodological science whose applications are bound to have quality implications.

In the current practice of statistical quality control, interest lies in the quality of the physical object produced; this is natural since the goal of factory managers and engineers is production. To the statistician however, the physical product is the end result of a significant quality-building process. Probability statistics helps build quality into an object because it builds quality into data, quality into decisions, and quality into performance. It does this by substituting probability sampling for judgment sampling, by controlling biased error instead of ignoring it, by using efficient methods of estimation instead of off-the-cuff methods, by employing design of experiments instead of traditional practices, by using effective methods of interpretation instead of rule of thumb, by designing the entire inquiry instead of doing each part in isolation from the rest. This is why probability statistics is such a powerful and versatile science when applied to the problems of research and management.

Statisticians do not yet know the full range of application of probability statistics to the problems of management; apparently what has been done to date has only scratched the surface. Experience shows us however that it can be applied in the office as well as in the factory, to production as well as to research, to service operations as well as to factory operations, to finance as well as to manufacturing, to persons as well as to machines. The determining factor is not what is traditionally called the subject matter of the problem, but whether the solution of the problem in whole or in part can be found in the frequency distributions of key characteristics. (2)

It is not surprising therefore to find that probability statistics is being used to solve the problems of a tax agency like the Bureau of Internal Revenue. There are several possible areas of application. In the first place, the Bureau is charged by law with the responsibility of compiling annual statistics on income and taxes from various forms filed with the Bureau. When the base of the individual income tax was broadened, and as the number of business concerns grew steadily, the number of tax returns increased tremendously. Individual income tax returns now exceed 52 million, corporation returns total nearly 700,000 while partnership returns of income are close to 1 million. With such a large number of returns to process, the use of a probability sample instead of a 100 percent tabulation becomes a necessity.

A second area of application concerns the audit of tax returns. Clearly it is a physical impossibility for the Bureau with its present staff, or

even with a much larger staff, to audit every tax return every year. From the beginning the Bureau has used judgment sampling grounded in experience, as the basis of its regular audit program. Within recent years the question has arisen as to what role probability sampling might play in the Bureau's audit program.

An audit program calls for the use of probability sampling on a person basis in order to discover those who should file a tax return but do not. Since the usual audit system is based upon filed tax returns, it is obvious that the taxpayer who never files a return is never going to be subject to audit. The use of a probability area sample which gives every individual in an area such as a city or county an equal chance of being selected, provides an efficient way of finding out how large this problem is, where it is concentrated, and whether the error discovered is worth the cost of discovering it.

The third area of application lies in various verification and review functions not included under audit. One of these is the verification of punch cards, another is the review of investigative work, another is post audit, another is verification of coding operations, while still another is the verification of calculations and bookkeeping operations.

A fourth area of application is the control over the variability of the performance of personnel: clerical workers, card punch operators, typists, calculators, investigators. The control over the variability of the performance of an investigator for example might start in the training course, and certification of competence might be based upon whether his performance on simulated tax cases came within tolerated limits. Periodic checks could be undertaken to insure that variability in the field is also under control.

A fifth area of application is for the purpose of special operating studies. Often it is necessary to design a probability sample for the purpose of a quick one-time study for management purposes. We may want to make an estimate of a characteristic which we do not have; we select a random sample from a file. We may want to test how closely certain workers in the field are following a procedure; we select a random sample of their work. We may want to know how a retail price change compares with a tax change such as that on beer and spirits; a nation-wide probability sample provides the answer.

Still another area of application is found in the use of probability sample surveys of taxpayers, for the purpose of measuring attitudes toward taxes and tax forms, and for the purpose of measuring the effectiveness of a tax education program. It is also possible to design field tests for the purpose of testing the relative effectiveness of two or more different forms to be used in filing on a given tax. Thus far no applications of probability sampling in this field have been made.

Designing a probability sample for annual statistical reports.

In designing a probability sample to take the place of a 100 percent tabulation for annual statistical reports, it is necessary to design a sample which will give estimates with a sampling error no larger than that prescribed, and with no higher frequency of occurrence than a specified probability.

The problem can be illustrated by determining how large a simple random sample would be required to meet the following specifications:

a. the relative sampling error (p) in the estimated mean or aggregate is 1 percent.
b. the probability of getting this deviation from the mean must be no more than 5 percent. This corresponds to a normal deviate (x') with a value of 2.
c. the coefficient of variation (cv) of the basic tax or income characteristic being estimated, such as net income or deficit, is 2.

Two other conditions have to be met: sampling must be from an infinite population, and the mean or aggregate is normally distributed. The size of the random sample required is 160,000 and is calculated as follows:

$$n = \frac{x'^2 \; cv^2}{p^2} = \frac{2^2 \times 2^2}{.01^2} = 160{,}000$$

In other words, it would be quite possible to obtain an adequate estimate of this characteristic by drawing at random only 160,000 returns from the population of 52 million returns, or by using only about 0.3 of 1 percent of the total.

Actually in sampling individual income tax returns we do not use this sampling plan for a number of reasons. We know that stratifying the population by size of adjusted gross income, by type of returns, and by business and nonbusiness return, will greatly reduce the variability of basic estimates. This means that stratification will improve the precision of our estimates. On the other hand, income tax returns are assembled for administrative convenience into bundles of 100 returns, so that the bundle can be used as a sampling unit. However unless the returns are thoroughly mixed before being assembled into bundles, the use of the bundle will give estimates with higher sampling variances than will the use of the same number of returns selected at random without regard to bundles. Furthermore estimates on relatively rare characteristics, and for relatively small subgroups of taxpayers, are usually required so that a sample of 160,000 returns is too small.

The actual sampling rates for the various adjusted gross income strata into which the individual income tax returns were divided for the years 1949 and 1950, are as follows:

Adjusted gross income	Sample rate 1949	Sample rate 1950
Under $7,000	1/2 of 1 percent	3/10 of 1 percent
$7,000 to $25,000	10 percent	10 percent
$25,000 to $50,000	25 percent	25 percent
$50,000 and over	100 percent	100 percent

In 1949 the sample was selected on a bundle basis for returns with an adjusted gross income of less than $25,000; it was selected on an individual return basis for returns with adjusted gross income of $25,000 and over. Furthermore, for the group with adjusted gross income of less than $7,000 a one percent sample of business returns was selected in order to obtain adequate statistics for this group. In 1950 the sample was selected on an individual basis; for those bundles with adjusted gross income under $7,000 the sample consisted of the first return in every 3 out of 10 bundles, while for those between $7,000 and $25,000 the first ten returns in

every bundle were selected rather than every 10th bundle, as in 1949. This sample plan for 1950 resulted in a total sample of 680,000 returns, or about 1.3 percent of the total population of about 52 million returns.

In a similar way it is possible to design probability samples of corporation income tax returns, and partnership returns of income. A corporation sample that will give adequate estimates of most characteristics for most of the more common subclasses requires about 100,000 returns or about 15 percent of the population. This design calls for stratified random sampling based upon the individual tax return, not the bundle, as the unit of sampling. A fairly high proportion of the population has to be used because in order to get adequate estimates by subclasses the largest corporations have to be sampled 100 percent - anywhere from the largest 10,000 to the largest 25,000 returns depending upon one's purpose. Even so, a tremendous amount of paper work is eliminated by using probability sampling instead of a 100 percent tabulation.

A method has been devised which allows a probability sample of tax returns to be selected as these returns are moving past some processing point in the tax agency. (3) This method, which features the use of punch cards and sampling boxes, not only provides a way of selecting a stratified random sample but gives complete control over the sampling selection operations. Furthermore the method is efficient and flexible so that it can be inserted into a routine of operations without causing any bottlenecks. This method was developed jointly by the Bureau of Internal Revenue (BIR) and the Federal Trade Commission (FTC) for the purpose of drawing probability samples of corporation income tax returns for 1949. The estimated population, the sampling rate, and the size of the samples, by size of corporation, are given in the accompanying table.

Probability samples of corporation income tax returns — 1949

Asset size class ($1,000)	Estimated population[a]	BIR sample[b]		FTC sample		Total sample number
		rate	number	rate	number	
Unknown[c]	57,000	1:15	3,800	1:10	5,700	9,500
0-50	235,000	1:90	2,600	1:60	3,900	6,500
50-100	96,000	1:30	3,200	1:20	4,800	8,000
100-250	97,000	1:18	5,400	1:9	10,800	16,200
250-500	43,000	0	0	1:7	6,100	6,100
500-1,000	25,000	0	0	1:4	6,200	6,200
1,000-5,000	27,000	0	0	3:5	16,200	16,200
5,000 and over	10,000	0	0	1:1	10,000	10,000
Total	590,000		15,000		63,700	78,700

a Active corporations filing a corporation income tax return.
b The Bureau of Internal Revenue restricted its sample to that portion of the population with assets under $250,000 and with no balance sheet.
c Some returns do not have a balance sheet, or the balance sheet is incomplete.

Some comments are relevant to this sample design. The principle of optimum allocation was used to allocate the sample to the different asset-size strata. The sample for the Bureau was designed on the basis of an estimated population of 485,000 returns; actually this number turned out

to be about 507,800 so that the sample obtained was somewhat higher than the 15,000 aimed at.

A probability sample of partnership returns of income can be designed to meet similar requirements for estimates. Assume that we have 950,000 returns, and that the largest 25,000 are included 100 percent; that leaves 9,250 bundles of 100 returns each. Now let us assume that the selection of one return per bundle is sufficient for the job at hand. That means a total of 9,250 plus 25,000 or 34,250 returns. If the size of a bundle is 100 and the average variance within a bundle is 52, and we sum over 9,250 bundles, then the standard deviation of the estimated total for this design is $\sqrt{9{,}250 \times 100^2 \times 52}$ or 69,354. Since the mean is estimated to be 5 per return, the estimated aggregate is 4,625,000. The relative sampling error then is $\frac{69{,}354}{4{,}625{,}000}$ or 1.5 percent. Actually the error will be less than this because the area sampled 100 percent (which has no sampling error) accounts for about one-third of the total income. This means that the actual sampling error for the grand total is two-thirds of 1.5 percent, or about 1 percent.

If random samples of 5 are taken from each bundle, then the standard deviation of the estimated aggregate is $\sqrt{\frac{9{,}250 \times 100^2 \times 52}{5}} = 31{,}016.$ The percent error in the sampled area is $\frac{31{,}016}{4{,}625{,}000} = 0.67$ percent. For the grand total the error is about 0.46 percent. Actually the gain in the precision of the over-all estimates is not proportional to the increase in sample size; however this is the price one has to pay in order to improve the precision of estimates of characteristics of small classes and rare items. In this latter case the total size of the sample is 25,000 plus 46,250 or a grand total of 71,250 returns.

From this discussion of sampling design it is clear that probability sampling compared with 100 percent tabulation represents a very sharp reduction in the amount of paper work involved in processing and in handling these returns, without any very serious loss in information. Indeed if the probability sample is that of audited returns we may find that the data from the sample are more accurate because the bias in unaudited returns may average higher than the sampling error due to random selection of audited returns.

Designing a probability sample for audit purposes

Probability statistics including probability sampling can be used in audit work for a number of different purposes. In the first place, by audit we mean careful examination of the tax return of a taxpayer; in one kind of audit this examination is carried out by mail or telephone without directly contacting the taxpayer, while in another type of audit there is an actual examination of the taxpayer's books and records.

Probability sampling may be used for purposes of estimation, for purposes of selecting cases for audit, for purposes of checking or reviewing audit work, for purposes of sampling inspection. It may be used therefore both to control the errors of the taxpayer, and to control the performance of the investigator.

In order to get the maximum benefit from the audit sample program it is necessary to obtain high quality data; this is done in the following ways: the entire program is carefully planned, the sources of bias are control-

led, relevant data such as the number of hours spent on examining each sample return are collected, probability sampling is used, and the data are subject to statistical analysis.

One of the most obvious uses of such an audit sample is that of defining the problem of noncompliance — its magnitude and extent — and to indicate where to concentrate audit resources for the purpose of correcting the most tax error per man-hour of investigation. A probability sample of 160,000 returns was selected from all individual income tax returns filed in 1948, and estimates made therefrom for the entire population. The major findings which were released to the public by the Bureau in May 1951, are as follows (4):

1. About 1 out of every 4 individual income tax returns is in error relative to tax.

2. The total amount of tax error made is about 1.5 billion dollars.

3. Of the number of returns with tax error, 90 percent are in favor of the taxpayer, while 10 percent are in favor of the Government.

4. The 1.5 billion dollars of tax error was made by taxpayers reporting $7.4 billion. The total tax reported by all taxpayers was $15.5 billion.

5. The average amount of tax error increases steadily as income increases.

6. The frequency of tax error among business returns is about twice that among nonbusiness returns.

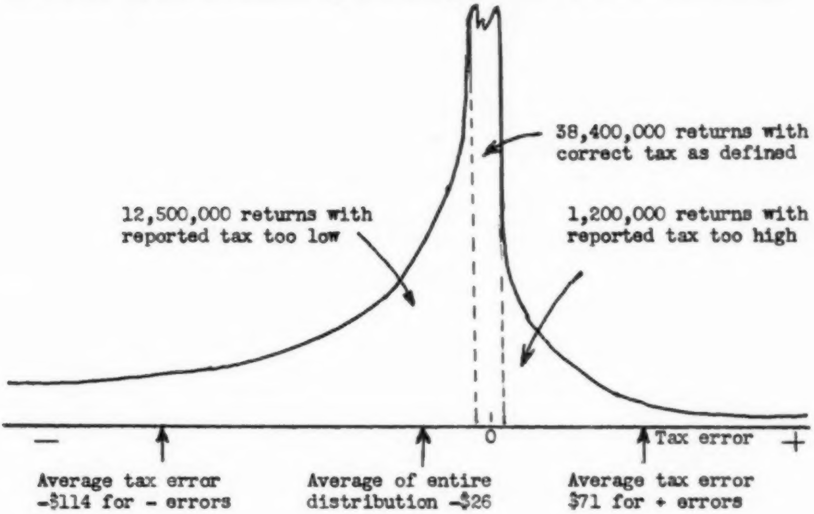
7. The major source of tax error is unreported or underreported income. Personal deductions and exemptions are other major sources of error. Arithmetic errors made on the tax return are a distinctly minor source of tax error.

8. The frequency distribution of individual income tax error based on these data, is a highly peaked highly skewed distribution.

In this probability sample, the number of hours required for the investigation of each return was recorded, and used to obtain a ratio of the amount of tax error corrected per man-year. Estimates of this ratio were obtained for a wide variety of classifications of taxpayers — by type of tax return, by type of business, by type of tax error, by size of refund. From these estimates it was possible to determine what kinds of returns to select for audit in order to correct the maximum amount of tax error per man-year of investigation. The relating of man-hours to tax error has been very illuminating and productive.

Probability sampling for audit purposes is being applied to both individual income tax returns and to corporation income tax returns. The audit sample for individual income tax returns is a subsample drawn at random from the random sample used for statistical purposes. The first audit sample included about 160,000 returns, but later audit samples have been smaller with more emphasis on sampling business returns. A major purpose of these probability samples is to provide estimates which can be

Certain characteristics of the distribution of tax error based on 1948 individual income tax audit sample data applied to 52.1 million returns



used to point to the most productive areas of audit examination — to the types of returns which can be readily identified and which result in the maximum amount of tax error being corrected per man-hour of examination.

The probability sample of corporations for audit purposes was limited to a population of about a half million corporations most of which had assets under $250,000 because this area lends itself more readily to a feasible sample program. This sample was drawn from the 1949 returns on a stratified random basis, and consisted of about 16,000 returns. The field work on this sample has been completed, the tabulation is well under way, and some preliminary results are now being obtained. It is planned to use this sample to define the problem and to indicate where the maximum amount of tax error can be corrected with a minimum amount of manpower.

The initial design of these audit samples could not be very good technically because of the almost complete lack of any knowledge of the frequency distribution of tax error. As we gain more knowledge about the characteristics of tax error, we shall be able to design much more effective probability samples. We shall always be limited, however, by the fact that the coefficient of variation of tax error, is relatively high compared with that of most economic and industrial characteristics (that is the standard deviation of the distribution is high relative to the mean, sometimes being 3 or 4 times as large as the mean). Much depends however upon whether we shall be able to find one or more bases of stratification which are effective in accounting for the variability of tax error.

A simple problem in applying probability sampling to tax audit

Suppose that it is proposed to use random selection as one basis for choosing filed income tax returns for the purpose of a field audit or investigation. The question arises as to how effective such a plan would be. It is possible to throw some light on this question by direct application of a simple principle of probability statistics, providing that the problem is restated as follows: What is the probability that a taxpayer will be selected 0, 1, 2,...... times during his tax lifetime, if the selection of the taxpayer is random, and the sample thus drawn is a certain percentage of the filed returns?

Assume that we have 52 million tax returns filed annually, and that the present tax system continues indefinitely. Assume that we draw repeated random samples of 1, 3, 5, and 10 percent from this population of tax returns. The probability of anyone being drawn as the first sample element is 1 in 52 million, or 0.0192×10^{-6}; the probability of being drawn as the last element of a 1 percent sample is 1 in 51,480,000 or 0.0194×10^{-6}. The probability of being the last element drawn in a 10 percent sample is 1 in 46,800,000 or 0.0214×10^{-6}. For all practical purposes the probability of selection is constant.

In this problem it would be possible to work out various answers depending upon how many years there are in a tax lifetime, a value which could vary all the way from one year to about 70 years. For the present illustration we shall take 45 years as an estimate of average tax lifetime. On the basis of these statements we can answer the question in the following way. The probability of a taxpayer being selected 0, 1, 2, 3,.. ....45 times during his lifetime is given by the successive terms of the binomial $(Q + P)^{45}$, where P is 0.01 for a 1 percent sample, 0.03 for a three percent sample; 0.05 for a five percent sample, and 0.10 for a 10 percent sample. The probabilities of being selected a specified number of times for each of these four possibilities, are as follows:

Number of times selected	Probability of occurrence: 1 percent sample	3 percent sample	5 percent sample	10 percent sample
0	.636	.254	.100	.009
1	.289	.354	.236	.044
2	.064	.240	.273	.107
3	.009	.107	.206	.170
4	.001	.035	.114	.198
5 or more	.001	.010	.071	.472
Total	1.000	1.000	1.000	1.000

These figures show that the probability of not being selected at all decreases from about 64 percent for a 1 percent sample to about 1 in 100 for a 10 percent sample. In other words, we have to select a 10 percent random sample in order to reduce to a very samll amount the probability of not being selected at all during an individual's lifetime. In order to do this we have to increase the average number of times from about .01 x 45 or .45 for a one percent sample, to about .10 x 45 or 4.5 times for a 10 percent sample.

The probability values given above are based on 45 years; for those who pay taxes for more years the chances are higher that they will be selected at least once; for those who pay taxes for fewer years the chances of being selected are less.

Unless a tax agency audits about 10 percent of the tax returns selected on a random basis, the probability of escape during a lifetime is very high. Many agencies may find such a sample size prohibitive.

It should be emphasized that this is a simple example of how probability statistics can be applied to analyze a problem. An even more important consideration than the probability of escape is the fact that since about 75 percent of the returns are free from error, simple random selection results in drawing an excessively large sample from those with acceptable tax returns, a sample which is largely though not completely wasted. A more effective way is to isolate groups of taxpayers where the probability of tax error is high and to concentrate the sample in that area. In other words the principle to follow, so far as it is possible and feasible to follow it, is that of sampling groups of taxpayers with probabilities proportional to the magnitude of the tax errors made.

<u>The use of analysis of variance in designing probability samples</u>

Finally we wish to add a note on how analysis of variance can be used in designing probability samples. This technique can be used in several different ways: it can be used to test the effectiveness of stratification or subdivision or classification in removing or explaining variation. It can be used to obtain unbiased estimates by eliminating the effect of certain factors or components. It can be used to test how much is lost or gained by using a group sampling unit instead of an individual element as a sampling unit. It is this latter use which we wish to describe.

Until recently the Bureau has been using bundles of 100 tax returns as sampling units. The bundles were easy to handle, fitted in with the regular administrative procedures, and there was little or no loss over simple random sampling due to the fact that the returns were fairly well mixed before being bundled. However recent developments have led to a departure from this method of sampling. There is a growing tendency in Bureau operations to physically segregate various kinds of returns before bundling — by type of return, by problem case, by business and nonbusiness, and in many other ways — so that the bundles represent more and more a stratification of the population. It was recognized that under such conditions, the use of the bundle as a sampling unit would mean an increase in the magnitude of the sampling variation to which the estimates were subject. An earlier application of analysis of variance to a random sample of 140 bundles of 1947 partnership returns of income selected from 35 districts, led to a similar conclusion relative to the use of bundle sampling of partnership returns. The summary of this analysis is given below where the key variate used is net income or deficit.

Attention is directed to the mean square of each component. There is a highly significant difference between districts so that stratification by this factor would be effective. There is also a significant difference between bundles within districts indicating that there is some additional variation which would not be eliminated by the stratification by districts.

What this analysis suggests is the use of bundles, not as sampling units, but as strata. If this is done then the best estimate of the population standard deviation is $\sqrt{52}$, or 7.2. For a random sample of 100

returns this would mean a standard error of estimate of $\frac{7.2}{10}$ or .72 compared with a value of about 1.1 if bundle sampling were used, a very significant reduction.

Component	Degree of freedom	Sum of squares	Mean square
Between bundles	139	16,735	120.4
Between districts	34	9,168	269.6
Between bundles within districts	3	265	88.3
Interaction districts x bundles	102	7,302	71.6
Within bundles	13,517	698,446	51.7
Total	13,656*	715,181	52.4

* The bundles averaged about 97 returns, rather than 100; this difference is not of any significance.

NOTES

(1) The statements made herein, with the one exception noted, are those of the author and hence are not to be interpreted in any way as official pronouncements of the Bureau of Internal Revenue.

(2) For a discussion of the broader aspects of the problem see A. C. Rosander, Quality Control through Probability Statistics, Industrial Quality Control, November 1951, pp. 34-36.

(3) A. C. Rosander, R. H. Blythe, Jr., and D. W. Johnson, Sampling 1949 corporation income tax returns, Journal of the American Statistical Association, June 1951, pp. 233-241.

(4) The Audit Control Program — a summary of preliminary results, May 1951, United States Treasury Department, Bureau of Internal Revenue, Washington, D. C.

A SURVEY AND EVALUATION OF TYPES OF QUALITY CONTROL EDUCATION

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The opportunities for education and training in quality control have developed hand in hand with the acceptance of the art as a management tool. Indeed, quality control may be unique in the area of scientific management because in many cases acceptance has been the direct result of formal training rather than the reverse. It is the purpose of this paper to review the present development of training and education, and to raise some questions about what the future shall be, and in particular, what part the American Society for Quality Control shall play in that future.

It must be remembered that the pioneer work in this field followed the tradition of slow development and acceptance. The work done in the twenties at the Bell Telephone Laboratories by Dodge and Romig (1) and Shewhart (2) in the first approach to scientific sampling and the invention of the control chart can scarcely be said to have taken American Industry by storm. By 1940 there were probably not more than a score of the larger companies which had personnel interested in these ideas. With World War II came the series of federally sponsored training activities for industry culminating in the Engineering, Scientific and Management War Training programs, offered in cooperation with schools and colleges throughout the country. Under the Office of Production Research and Development, War Production Board, a Quality Control Section was set up under the direction of Dr. Holbrook Working of Leland Stanford University and Dr. Edwin G. Olds of the Carnegie Institute of Technology (3). Thirty-four of the famous "eight-day courses" were given from coast to coast, and 1885 men from over 900 organizations took part. An equal number attended the special one-day opening or promotional parts of the program.

This venture in training served two useful purposes. Hundreds of industrial firms made immediate applications of the principles learned and saved the American taxpayer countless millions of dollars. Of more permanent significance was the creation of local quality control groups and societies by the graduates of the eight-day sessions. The American Society for Quality Control was formed by the union of these scattered groups, so it can be truly said that the Society was founded on an educational base. As a professional society its primary function is the encouragement and dissemination of knowledge. The three committees of the Society having this as their main function are the Editorial Board, the Brumbaugh Award Committee, and the Committee on Education and Training. Every Sectional meeting, Regional conference and National convention is an adventure in learning.

How are we doing with this training job? At present we have several regularly scheduled training programs sponsored by universities, evening programs sponsored by colleges and local sections of the Society, conference quickies, promotional meetings, in-plant training programs, a flood of books and articles, and a trickle of college-trained men. Have we a right to be satisfied? Your Committee on Education and Training, with Mr. A. C Richmond of the International Harvester Company as Chairman, would like to know what you think.

Intensive Short Courses.

The half dozen ten-day training programs sponsored annually by various universities are outgrowths of the war-time ESMWT programs. They attempt to present the principles behind control charts and acceptance sampling, to give some practice in the mechanics of these tools, and to explore the practical problems encountered in the administration of them. Early this year a correspondent asked if he could reasonably expect to become an expert, in the sense of a consultant, by taking one of these programs. The answer is obviously and emphatically "No." No one becomes an expert in any field by taking a course or series of courses, and all that these short courses can hope to do is to give a man enough of a start so that he may begin to practice on a sound basis and by continuing to study and practice, finally develop into a reasonable competence if not into an authority. This is a statement, not a criticism. What can we expect of ten days and the average person - one might say even the superior person? The strong points of these programs are many. They are generally well organized and taught by well qualified personnel. Once embarked, the student finds he is not distracted by other problems, nor indeed does he have much time for them. The basic principles, upon which a plant program swims or sinks, are carefully presented, drilled and reviewed. Because they carry a fee and in most cases involve absence from the home plant, it can be hoped that management sends properly qualified men, both by background and position, to take advantage of them.

On the negative side, it is true that while the basic principles are few and well presented, they come rather fast for all but the trained student to grasp, and it is plant personnel, not students who must put them into use. This means that the course must be followed by some form of review and study. It may also be argued that these courses are so far from the home plant that they lack reality, but this objection is more than balanced by the exchange of ideas between the various students, and with the instructors.

The same arguments can be advanced in behalf of or against the few "advanced" courses offered, which generally take up a review of the basic material, plus work in the fields of correlation analysis, significance testing, and design of experiments.

Evening Sessions.

In a majority of the industrial centers of the country evening sessions are offered by colleges, technical schools, local sections of the A.S.Q.C., and other sponsors. They may be credit or non-credit, free or on a tuition basis, and may run from eight to sixteen two-hour sessions. The advantages are obvious. They may be attended by persons who could not go out of town, and they provide for a period of rest and reflection between doses of theory and class room discussion. They are likely to be staffed by adequate instructors, and follow in general the outlines of the ten-day programs.

On the unfavorable side, the opportunity for reflection and study is apt to be neglected, unless the course is credit bearing. Many "practical" persons may be repelled at the first sign of theory, and drop out before the application is thoroughly reviewed and developed. This may in part be overcome by proper arrangement of the topics. To be honest, this weeding out process may be a real advantage both to the individual and to his company. A major weakness is the usual lack of a laboratory

session, in which the principles and practice are actually used by the student under instructional supervision.

One- and Two-Day Sessions.

If an expert cannot be developed in ten days, the "quickies" must fall short of the level of competence. They do serve a very real and useful purpose. They may be utilized as a brief but effective supplement to personal coaching, and as an excellent promotional device for the top executive who cannot or will not attend a longer course. Many who attend such a program, usually sponsored by the Society at the national, regional or local level, are stimulated to participation in a longer session. On the other hand, a person who has taken the full dress program will sometimes attend the shortened version for review purposes. Such persons invariably comment on the ability of the instructors, an excellent testimony to their own growth and development.

The In-plant Program.

Because of the variety of purposes, methods, lengths and instructional abilities, the in-plant program is difficult to discuss. As we get close to the actual scene of operation of a quality control program, we see more clearly the need for different levels of training and approach. A manager or director of quality control should ideally be an educated, not a trained man. He should thoroughly understand the technology of his industry, he should understand the problems of production and inspection, and should appreciate and practice the scientific evaluation of data by statistical and other methods. The in-plant course is not for him, unless he is to be the instructor or coordinator.

Top management needs an over-all idea of the principles, such that intelligent decisions can be rendered on the evidence marshalled by the quality control staff. While a base can be laid at the "quickie" sessions, only practice and persistence will lead to assimilation of these techniques into the personality of management. The average president or production manager would profit by actually pushing a pencil, calculating and interpreting these useful aids to judgment.

The bulk of training in the plant will be pointed to the quality control and inspection personnel, and to the production foreman and his aids, the standards and methods men. About eight hours is enough for the average foreman. If he wants and takes more he is probably a good bet for a higher supervisory position. The rank and file of the inspector and quality control people of whatever title and rank should get the works. This helps to provide capable men for their immediate jobs; it also serves as a guidepost for promotion. Interest and talent is found in the most unexpected places.

Finally, it can be argued that the indoctrination of new personnel at all levels should include a well prepared explanation of the economic importance of quality, the place of the newcomer in this quality program, and an explanation of the techniques actually used in the plant for quality protection. Needless to say this indoctrination will be futile unless management practices what is being preached.

Education at the College Level.

A review of this training and educational problem would not be complete without a look at the college student. Dr. Olds, in a companion paper (4) presents the case of the engineering student, and I shall not dwell on that, except to venture a guess that here is the cradle of the quality manager of tomorrow. Three years ago the Committee on Education and Training (5) found 35 engineering colleges out of about 130 offering some work in quality control, and a somewhat larger group offering courses in statistics. The word "offering" is used advisedly. In the writer's own institution, out of a total of approximately 900 graduating seniors in 1951 about 43 took courses in quality control and practically none in statistics.

What shall be done for the men in the management courses in colleges of commerce? And what about the mathematicians? We must have a steady supply of theoretical statisticians who are willing and able to help us find new solutions to our problems. Some of these men will find a place in the larger industrial organizations, while others will locate in the colleges and in research organizations.

Scope of Training and Education.

Up to this point, little has been said about what constitutes an adequate background for general quality control work aside from statistical procedures. Blueprint reading, contracts and specifications, inspection procedures, test codes, functional design and personnel relations must all be understood by the capable quality control man. As a Society, we cannot assume responsibility for all these factors, nor for all the skills and knowledge that the general factory personnel must possess to do a quality job. There are some general principles that we must stand for.

All supervision, including sales and purchasing, must appreciate the philosophy of the calculated risk, with sufficient understanding to accept the judgment of the statistically-trained quality control man. Supervision must understand that quality is the responsibility of the design and production forces, and that the act of inspection does nothing in itself to make a satisfactory product. Quality control recommends; action is taken by engineering and production.

This leaves plenty for quality control to contend with. At the level of action, there is the evaluation of product and process quality, and active aid toward the corrective action. Inspection equipment and procedures must be accurately and honestly evaluated. The following list of topics is a minimum that the quality control man must really understand:

1. The idea of variation and its measurement, and the concept of random and assignable causes.

2. The relation between the variation of averages and individuals, and the proper comparison of process capability to specification tolerances.

3. The meaning and calculation of the operating characteric curve, the average outgoing quality curve, and the average sample number. He

must learn to judge the economic effects of any sampling plan, whether it be rule of thumb, taken from a published set of tables, or tailor-made on a scientific basis.

4. The scientific comparison of methods or processes.

5. The measurement of effectiveness of substitute tests.

6. The translation of his technical skills into the universal language of the dollar.

It should not seem necessary to make up such a list, but the slow progress or outright failure of many promising quality control programs can be traced directly to the quality manager who does not understand or does not believe in these principles. He sacrifices logic for guesswork, hard mental calculation for speed, and in the end he sacrifices all.

Conclusion.

We are back to the original question. Are we satisfied with the opportunities and the methods of our present training? Do our in-plant programs and external courses give us what we want and need? This paper presents nothing new, but merely points up some problems for discussion. The success of this session will depend on you, on your willingness to ask questions. It will depend on your ability to help answer them, for your speakers today do not claim to know all the answers. Some of the questions may never be answered, but the search will be worthwhile.

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SOME PROBLEMS IN SAMPLING ACCOUNTING RECORDS

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The material used in this talk is largely taken from a paper presented two years ago at a conference on Business Applications of Statistical Sampling Methods under the sponsorship of the University of Illinois and the Chicago and Urbana chapters of the American Statistical Association. It is not intended to cover the subject in comprehensive fashion, but merely to mention some applications with which I happen to be familiar.

Purposes of Sampling

When we sample accounting records, or business records of any kind, we usually have one of these purposes in mind:

1. To get information that's available from the records but that is not ordinarily summarized.

2. To supply a framework for making some kind of survey.

3. To provide a basis for testing the accuracy of the information shown on the records.

An illustration of sampling with the first purpose — to obtain information not ordinarily summarized — is the sampling of our customers' accounts to determine their local telephone usage. For most of our customers in the city of Chicago, there is a tabulating card that shows the monthly usage of local service, and the charge for such service. We need to know this average monthly usage for customers in each rate classification, and the distribution of that usage; that is, the proportion of our customers that use 0-10 messages per month, the proportion number using 11-20 messages and so on. It would be very expensive to summarize this information 100 per cent; and so for about 25 years, we've been relying on sampling procedures.

Samples with the second purpose mentioned — to supply a framework for some kind of survey — are taken periodically in connection with our attempts to measure the attitude of our customers toward the telephone company, particularly toward the service we furnish and the charges we bill for it. Accounting or plant records, and sometimes telephone directories, are used to select the sample customers. These customers are then interviewed, by telephone or otherwise, and asked to give answers to a set of questions. The analysis and summarization of these answers yields the information we want. Similar surveys have been taken in the last year or two to measure the attitudes of supervisory employees toward the Company and higher management.

Another kind of sampling we do occasionally is of particular interest to engineering statisticians. This is the sampling of our plant records and engineering records to provide a framework for appraising the per cent condition of our telephone property. This is one of the things we ask the regulatory commissions to take into account in fixing the rates we charge for telephone service.

The third purpose of sampling our records — to test the accuracy of the records themselves — is essentially the same as when sampling inspection is employed in a factory. We call it sampling verification; and several accounting operations are regularly inspected under single or sequential sampling plans. Consideration is now being given to the use of control charts to analyze sample data as to inventory shortages. It's my personal opinion that we have hardly begun to utilize the tremendous possibilities in these various quality control techniques in all phases of the telephone business.

Methods of Selecting the Sample

Samples can also be grouped into about three different classifications according to the general techniques used to select the individual items that make up the sample. These general techniques are —

1. Judgment sampling.
2. Systematic sampling.
3. Random sampling.

In judgment sampling, the particular items that make up the sample are determined by some one who is supposed to be familiar with the population in which we are interested and to be able to use good judgment in selecting the items that are to constitute the sample. In systematic sampling, we start with a particular item at one end of a population that has previously been arranged in some kind of sequence, and we choose every nth item — for example, every 10th item if we want a ten per cent sample, or every 100th item if we want a one per cent sample. In random sampling the sample items are selected in such manner that all items in the population have equal chances of being included in the sample, and the inclusion or exclusion of one item has no bearing on the chances of the other items.

Each of these three methods of sampling has certain advantages and disadvantages as compared with the other two methods; and no one of them is invariably the best method to use. Judgment samples are frequently necessary when we need data in a hurry, or when we are interested in only a part of a population. For example, you would not inspect manufactured parts by taking a random sample of all their dimensions. You would inspect only those dimensions that are most important. Similarly, in verifying clerical work, we look for types of errors that cause the most trouble; and we pay more attention to new employees than to those with more experience. But a judgment sample is no better than the judgment of the person who designates the items to be selected. And different persons may get widely different answers to the same question.

Systematic sampling, where every nth item is selected, is easy to explain and to supervise. Moreover, if the first item is chosen at

random from the first n items in the population, the element of personal bias in the selection will be eliminated. It usually has certain other advantages. Thus, if records of telephone poles are numbered according to geographical location, a systematic sample of these records will have the correct proportions of poles from each geographical area, or very nearly so. On the other hand, the sample measurements may not be at all representative if there are repeated cycles in the property we are trying to measure. Suppose, for example, we were to try to measure telephone usage on the basis of a sample of every hundredth telephone number. It happens that telephone numbers ending in double zero are usually assigned to customers with large private switchboards, while other numbers are assigned to these customers less frequently. For this reason, if our sample happened to include only telephone numbers ending in double zero, the average usage of our sample customers would be much higher than if it included only numbers ending in 58, for example.

The chief advantages of random sampling are (1) that the sample measurements will tend to agree with the measurements for the population as a whole, and (2) that the extent of this agreement, which we call the precision of the sample, can be estimated from the sample itself. This kind of sampling is best to use where the results are to be offered in evidence before a court or a regulatory body. It can also be used in many situations where data are gathered for administrative purposes. And it's necessary to use it in investigations where the theory of probability is called into play to test some hypothesis about the population sampled. We are coming to use it more and more in our business.

How to Select a Random Sample

Random sampling would probably be used more widely if more people knew how to go about it. The necessary steps might be outlined as follows:

1. Decide on the units into which the population is to be divided for sampling purposes.

2. Number these sampling units.

3. Make the selection by referring to a table of random numbers.

4. Count or measure the sampling units that correspond to the random numbers.

The choice of sampling unit will depend on what we are interested in knowing, and on what records are available. To take a concrete example, let's assume that we wish to find out the average number of local calls per telephone subscriber per month. To select our sample subscribers, we might use any one of several records, among which are the following:

Accounting department records of service and equipment.
Address plates used in preparing bills.
Bill stub files in the accounting department or in the business offices.

Plant department records of equipment.
Traffic department records of subscriber lines.
Telephone directories.

Or, we might select our sample without even referring to records, as by selecting jacks on the switchboards, or by simply picking telephone numbers at random.

Now, let's turn to the problem of numbering our sampling units. In the case of telephone customers, the problem is easily solved, since our customers are already numbered. In Chicago, we reach another telephone by dialing two letters and then five digits. But since each letter dialed corresponds to a digit, as you can see by looking at one of the dials, we have the equivalent of a 7-digit numbering system. In effect, then, each customer has a number somewhere from 0 to 9,999,999, inclusive. Since there are only about 900,000 numbers actually in use, it's obvious that about 91 per cent of the 10 million possible numbers actually do not correspond to telephone customers. This is not too important, however. But there is a problem due to the fact that some customers have more than one telephone number. We'll consider it later. The important considerations are (1) that each number identifies a particular customer without any possible ambiguity, and (2) that the record of local usage corresponding to a particular number can readily be located.

Suppose our customers were not already numbered. It would be quite a job to go through our records and write down a serial number for every customer. But this would not be necessary. Assume that we wish to use a file ofcard records, one to a customer. Suppose these cards are kept in drawers, arranged in 100 tiers with 8 drawers per tier; and that no single drawer can possibly hold more than 2,000 cards. We could then assign each card a 7-digit number, letting the first two digits denote the tier, numbered left to right in some predetermined manner with 00 denoting the 100th tier; letting the third digit denote the drawer in a particular tier, counting down from the top; and letting the last four digits denote the card in a particular drawer, counting from the front. Given any particular number of seven digits or less, it would be possible to locate the corresponding card record in a few minutes, with no confusion as to which card is the right one. There would not be a card, or even a drawer, corresponding to every 7-digit number, of course; but again, this is not important.

In most sampling problems, there is some fairly simple way to number the population to be sampled.

The next step in our procedure is to select the random numbers. Tables of random digits are usually published in blocks of five or ten digits each. To select a set of 7-digit numbers, we turn to some page and block of numbers in a haphazard manner, and then begin writing down digits, seven at a time, in the order in which we find them in the table. In doing this, we may proceed horizontally, or vertically, or even diagonally across the page. When we come to the end of one page, we begin with the following page; and if we use up the last page of numbers, we start on the first page in the table. No problem is involved here unless we use up all the pages, in which case we shall have to turn to a new table

to obtain our quota of random numbers.

The last step is to find the card records that correspond to the random numbers written down. This procedure is usually facilitated if the random numbers themselves have been recorded on small 3" x 5" cards, and then arranged in numerical sequence. In many cases, of course, we shall have a random number for which there is no card record in the population we are sampling. In every such case, the random number must be discarded completely. In no case should some adjacent record or number be substituted for the record that is missing. Because of this discarding, it will usually be necessary to select more random numbers than the number of records we require in the sample.

Now we can turn to the problem of what to do when an individual has more than one telephone number. In such cases, it is necessary to adopt some arbitrary rule beforehand so that each such individual is particularly identified with just one of these numbers. Thus, each telephone customer having more than one telephone number has what is called a "key" number, which is usually the only one that appears in the telephone directory. Suppose we identify customers in this category with their key numbers. We can then adopt the arbitrary rule that one of these customers will be included in the sample only if a random number is selected that corresponds to his key numbers. In this way, each customer will have just one chance of being included in the sample. Unless some such rule is adopted, customers with more than one number will have more chances of being drawn into the sample than customers with only one number. This rule, of course, will also tend to result in discarding some of the random numbers selected.

Some Useful Formulas

Before selecting random numbers, we may wish to know how many we need to write down so that after discarding unusable numbers we shall be reasonably sure to have enough left to give us a sample of some specified size. I've worked out a formula for this and included it in an appendix which will be published as a part of the proceedings of this conference. Other formulas that have been found useful are also given there. Included are formulas for listing the distribution of the sample among the various parts of the population when the distribution of the population among these parts is known. Some such test should always be made wherever possible.

Usage Cards with Random Numbers

You may also be interested in some new ideas that have come up in the last year or two. One of these is a suggestion made by Professor John W. Tukey of Princeton University, who spends a part of his time at the Bell Telephone Laboratories. He's also a member of the American Society for Quality Control, the American Statistical Association, and other organizations. John's idea is to punch a three-digit random number in each I.B.M. card on which we record customers' usage. This random number would be permanently associated with the telephone number, and would be reproduced from month to month along with the telephone number when each month's

card file is established. A sample of almost any size could then be selected by machine sorting on these random digits. For example, if we wanted to select a random sample to include one per cent of our customers, we would select a two-digit number from a random number table and machine sort on those two digits. I believe this will prove to be a very useful idea.

Extreme Fluctuations

Another idea has to do with the verification of the usage records on our I.B.M. tabulating cards. The meter readings are subtracted and the charges for the additional local message units are computed by what is known as Type 604 electronic calculating punch. But before issuing our bills, we like to investigate cases where there are extreme fluctuations in the usage so that we can detect possible errors.

Now it happens that the Type 604 machine can indicate these extreme fluctuations automatically. Each tabulating card shows the usage for the previous month as well as the usage for the current month; and the machine will compare these two usages and select the lower usage. Let x represent the lower usage, and y the higher usage, for the last two consecutive months. The machine will multiply x by a constant, b, add another constant, a, and punch a hole in the card unless y is less than a + bx. This hole causes an asterisk to appear opposite the usage when it's printed, and warns us to look for trouble. We can choose the numbers a and b, to be wired into the control panel for this operation, provided we restrict these numbers to two digits. The problem is how to choose these numbers. For our purposes, it appears best to make a equal to 50, and b equal to 1.8.

In deciding what values to use for a and b, we need to consider two cases or situations where the formula will fail to accomplish what is desired:

1. Cases where there is something wrong with the usage records, but the application of the formula fails to reveal it.

2. Cases where the formula indicates something is wrong, but the usages recorded are actually correct.

Cases of the first kind, if not detected, will lead to incorrect billing for telephone service, and possible irritation to customers. Cases of the second kind will lead to a waste of time and money in looking for errors that actually do not exist. So far as possible both kinds of cases, where the formula fails to perform as desired, should be kept at a minimum. In practice, however, a combination of values of a and b that tends to eliminate most of the failures of one kind will lead to a large number of failures of the other kind. Some compromise has to be made, after taking into account the relative importance of the two kinds of failure. The problem is to find the best compromise.

Decision Functions

Problems similar to this have received considerable attention from statisticians in recent years. Essentially, it's the problem of de-

ciding whether a particular pair of values of x (the lower usage) and y (the higher usage) belongs to one or the other of two populations:

A. A population consisting of correctly recorded pairs of values of x and y.

B. A population consisting of recorded values of x and y where at least one of the two values is not correct.

Failures of the first kind described above are equivalent to errors in classifying an (x,y) pair that belongs to population A. Failures of the second kind are equivalent to errors in classifying an (x,y) pair that belongs to population B. The problem is to minimize the weighted sum of these errors, where the weights are selected to correspond to the relative importance of the two kinds of errors. Two general approaches to the solution of the problem have been suggested for two different situations with respect to the information available.

The first approach can be used where information has been obtained, from study data or otherwise, as to the joint distribution of the x's and y's in each population — that is, as to the proportion of each population that corresponds with each pair of x and y. Suppose we know this proportion, and the relative importance of the two kinds of failures to classify the (x,y) pair correctly. Then it's possible, in theory at least, to find a <u>decision function</u>, sometimes called a <u>discriminant function</u>, that will best solve the problem of classifying a particular pair of values of x and y.

The other approach to solving the problem is more suitable, if not necessary, when the distribution of population A is known or can be determined, but population B has an unknown distribution or is composed of heterogeneous elements such that any assumption about a fixed distribution would be unrealistic. This appears to be similar to the situation in many problems of quality control. In other words, when a process is in control, the variable inspected has a stable distribution; but when the process is out of control, the distribution seems to fluctuate erratically, if indeed a probability distribution can be said to exist.

The situation with respect to the problem considered here, at least at the present time, appears to be the one described for the second approach. I'll not describe in detail what we did to solve the problem. But in brief, we studied a sample of 10,000 usage cards to get the joint distribution of x and y for population A. Then we selected our constants a and b so that, as far as possible, the risk of deciding something is wrong when it really isn't has about the same value for each x. This risk was made approximately equal to the risks in quality control when the 3-sigma limits are used in connection with $\bar{X}$-charts.

<u>Other Problems</u>

There are many other sampling problems, of course, that have not been covered in this talk. For those who wish to explore the subject further, the best procedure I suppose is to read the textbooks and periodicals

in the field of statistics. A recent book that has many practical ideas is W. E. Deming's book, Some Theory of Sampling. It contains material that has not been available anywhere else.

Finally, we come to the problem of selling sampling procedures to our top managements. I think you may be interested in a little booklet I wrote to put across the possibilites of the control chart.

STATISTICAL TECHNIQUES FOR MANAGERIAL CONTROL

Introduction

The control of large business operations requires management people at all levels to keep and interpret performance indexes of many kinds. Examples of such indexes are volume of sales in dollars or other units of measurement, profit margin per dollar of sales, number of customer complaints, number of work units produced per employee hour, number of per cent of defective units, and number of days lost by employees on account of sickness or accident. More elaborate indexes computed by various weighting procedures are common.

The purpose here is to describe an approach to interpreting one of these indexes. This approach leads to objective answers to questions as to whether the position of the index indicates the need for investigation with a view to possible managerial action. It is being used successfully by hundreds of management people throughout the United States and in several foreign countries. While experience has been most extensive in the quality control of manufactured products, the same principles are applicable in other fields.

For illustrative purposes, the index discussed is assumed to measure some kind of performance at a division level. But the discussion also applies to indexes at the company level, and on down to indexes measuring the performance of an individual worker.

The Problem

Joe Smith is division manager for the X Corporation. On the wall behind him is a chart showing the recent behavior of a performance index for Joe's division.

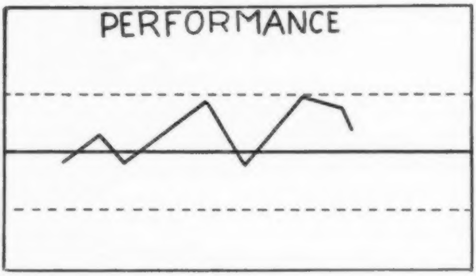
Yesterday's figure has just been plotted on this chart. It's two points below the previous figure. The question immediately arises,

IS THIS DROP IN PERFORMANCE SIGNIFICANT?

Knowing the right answer to this question is important. If the drop is significant, Joe should do something about it. He ought to find out what caused the drop, and take steps to bring about improvement. On the other hand, as Joe well knows, there are always some fluctuations up and down that don't mean anything. If Joe investigates every little fluctuation and tries to do something about, he will be wasting his time and the time of several other people who are trying to help him. Looking for trouble that does not exist can be very expensive.

Fortunately, Joe doesn't have to guess about the right answer. He knows immediately whether he should investigate. How he knows is outlined on the next page.

The Control Chart



A close look at the chart reveals some broken horizontal lines. Joe calls the upper line the upper control limit. The lower one is called the lower control limit. As long as the index stays within these limits, Joe doesn't need to worry. The fluctuations within this band don't mean very much. But if the index gets below the lower control limit, something is slipping. Joe had better find out why, and do it right away. On the other hand, if the index goes above the upper control limit, it calls for a celebration. A performance that good is no accident. Something new has brought about a real improvement. Joe had better see what this thing is, and try to make the improvement permanent.

A chart of this kind, with upper and lower control limits, is known as a control chart. It does two things for Joe. First, it shows him how his index compares with a standard index of performance, plotted as a heavy horizontal line midway between the control limits. Second, it shows him whether the difference between his index and the standard index is great enough to be of any significance. The interpreting procedure is quick and sure. All Joe has to do is glance at the chart.

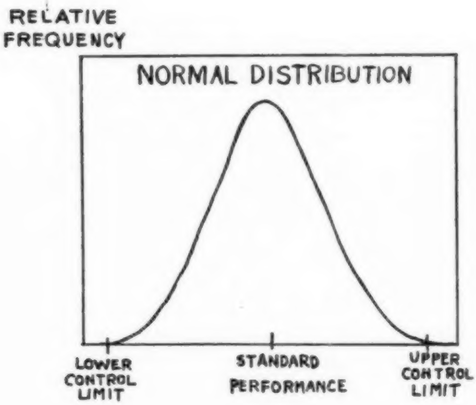
The trick, of course, is to design the control chart so that it will actually distinguish between fluctuations that are significant and those that are not. This trick is briefly described on the pages that follow.

Interpreting Fluctuations

The proper design of a control chart rests on a very important principle: If the fluctuations in any index are due to the combination of a large number of small chance causes, then these fluctuations will have a definite pattern, as shown by the diagram on the next page. From

this pattern, known as the normal distribution, a statistician can predict the relative number of times the index will fall between any two given values. In particular, he can compute two values outside which the index will practically never fall, and set these two values as the control limits. If the index ever does fall outside these limits, he can be pretty sure that some new, important cause of fluctuations has entered the picture.

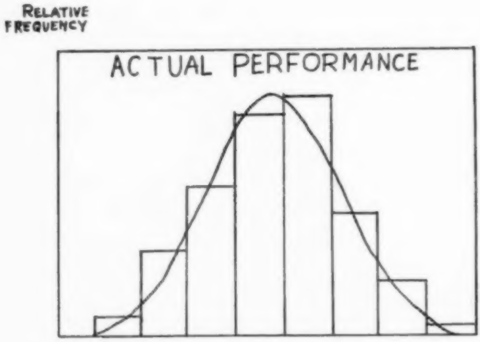
Joe Smith can make good use of this principle. As long as the fluctuations in his index are due to the combination of a large number of small chance causes, it will usually not be economical for him to investigate any given fluctuation, since the effect on the index of eliminating one or two causes would be too small to make the investigation worth the cost. On the other hand, when the fluctuations are assignable to one or two important causes, it will nearly always pay to investigate.



A properly designed control chart automatically sorts out the fluctuations between those due to important big causes and those due to unimportant little causes. That's the reason the chart is so useful.

Determining Standard Performance

The first step in designing a control chart for Joe consists in analyzing historical data as to actual performance to see whether the indexes follow the bell-shaped normal distribution. If so, the average of the indexes can be established as the standard performance level, and control limits can be computed by methods described in the textbooks on statistics and quality control. All the indexes used in making the computations will lie within these limits, and the performance is said to be in <u>statistical control</u>.



If some of the indexes used in the computations fall outside the control limits as initially determined, there are important assignable causes of fluctuation present. In that case, the computations should be repeated after excluding the indexes outside the initial limits. Further repetition may be necessary before all the indexes used in the computations will lie inside the revised control limits. The last revision will result in a tentative control chart that will be suitable for a time in helping Joe make decisions as to when action is necessary. The final revision must wait until Joe has eliminated those important causes of fluctuation.

The control chart approach not only helps Joe to answer the question, <u>Is a drop in the performance index significant</u>? It also helps to answer the more fundamental question.

IS PRESENT PERFORMANCE SATISFACTORY?

The answer is No if the performance is not in statistical control.

Other Control Techniques

The control chart is ideally suited for use by busy management people in the line organization to control measurable work by employees under their supervision. The chart is simple. It tells the story.

Statistical techniques are also available for other aspects of managerial control. Acceptance sampling plans, for example, are designed primarily for use in inspecting the quality of incoming materials with minimum expense. They are also suited to staff audits of the quality of work going out to customers or to other sections or departments. Such use should be preceded by statistical analysis as in designing control charts, so that the decisions as to the acceptability of the work will generally be the same as when the control chart technique is employed.

Continuous sampling plans are available for screening out enough defective work units to bring the average quality level up to some specified level. They are ideally suited to situations where a quality level is required that is higher than the standard index of quality as determined statistically. These situations, however, are likely to occur only where the specifications are fixed arbitrarily by people who are not acquainted with statistical quality control. The control chart principle, properly applied, nearly always results in maximum quality at minimum cost. It is being extensively used even where quality is a matter of life and death, as in manufacturing ordnance for the Air Force.

In Conclusion

Organizing a successful program for managerial controls requires the meshing of several kinds of skills or qualifications, as follows:

1. Statistical competence. The control chart approach is not a simple, one-shot proposition. It requires careful study before the chart is installed, and subsequent research from time to time to keep abreast of current developments. It should be supplemented by other statistical techniques.

2. Managerial know-how. The statistician's tools do not correct situations where performance is not up to standard. They merely point them out. Experience in the field is necessary to taking the proper action to bring about improvement.

3. Skill in human relations. The statistical approach leads to the setting of reasonable levels of standard performance, and unbiased judgments as to whether these levels are being attained. But proper indoctrination is desirable to get acceptance of these facts by both the people who do the work and the people who supervise it.

Where a program has been properly and carefully planned, managerial controls invariably lead to better performance without increasing overall costs. In most cases, the combination of the skills enumerated above reduces costs substantially.

Statistical controls work because they help management people take prompt action in problem situations that are most in need of attention. They prevent wasting time when no problem is present.

APPENDIX

SOME USEFUL FORMULAS IN SAMPLING ACCOUNTING RECORDS

INDEX

Subject

1. DETERMINING HOW MANY RANDOM NUMBERS TO SELECT

Suppose we wish to select a sample of size n from a population of N items. Suppose that each item in this population is assigned a serial number in such manner that no two items have the same number. It is not necessary that the largest serial number be equal to N; in other words, the largest serial number may be larger than N, and there may be serial numbers less than N that do not correspond to some item in the population.

Let

(1.1) $$M = 10^d$$

where d is a positive integer so chosen that M is the smallest integral power of ten that is equal to or larger than the largest serial number. Then a random sample of the population may be obtained by selecting numbers with d digits from a table of random numbers, and observing the item with serial numbers corresponding to there random numbers, provided we assign the random number with d zeros to the population item numbered M.

Of the random numbers selected, however, only the proportion

(1.2) $$p = N/M$$

will correspond to items in the population. Hence, if we select m random numbers, the usable numbers will tend to be equal to pm. To get n usable numbers, on the average, we set

(1.3) $$m = n/p.$$

In some cases, however, the actual number of usable numbers will turn out to be less than n/p. This may put us to the inconvenience of selecting more random numbers to get the desired sample quota. To make this unlikely, we can allow a little margin in the size of m. A simple way to do this is to set n equal to the expected value of n_a, the actual number of usable random numbers, plus some multiple of the standard error of n_a.

The average, or expected value, of n_a is

(1.4) $$n_a = mp.$$

Its standard error is

$$(1.5) \qquad n_a = \sqrt{mpq}$$

where

$$(1.6) \qquad q = 1 - p$$

Following the suggestion in the preceding paragraph, we first write

$$(1.7) \qquad n = n_a + k\sqrt{mpq}$$

for arbitrary k; whence

$$(1.8) \qquad m = \frac{n}{p} + \frac{k^2q}{2p}\left[1 + \sqrt{1 + 4n/(k^2q)}\right].$$

For k = 2, this formula may be written

$$(1.9) \qquad m = \frac{n}{p} + \frac{2q}{p}\left[1 + \sqrt{1 + n/q}\right].$$

Example 1

Number of telephone customers	800,000
Largest possible serial number	9,999,999
Required sample size	1,000

Computation

$N = 800{,}000 \qquad M = 10{,}000{,}000 \qquad d = 7.$

$p = N/M = .08 \qquad q = .92 \qquad n = 1{,}000.$

$$m = \frac{1{,}000}{.08} + \frac{1.84}{.08}\left[1 + \sqrt{1 + 1{,}000/.92}\right]$$

$$= 12{,}500 + 782 = 13{,}282$$

2. STRATIFIED SAMPLING

The following formulas are useful when it is desired to distribute a sample over different parts, or strata, of a population so as to determine the overall mean of the population with the best possible compromise between precision and cost.

Suppose a random sample is to be selected from each of several large classes, or strata, in a population where

(2.1) k = number of classes or strata,

(2.2) N_i = size of i th class,

(2.3) σ_i = standard deviation of i th class,

(2.4) c_i = sampling cost per observation for the i th class,

(2.5) $N = N_1 + N_2 + \ldots + N_i + \ldots + N_k$ = total size of population,

(2.6) $w_i = N_i \div N$,

(2.7) n_i = size of sample from i th class,

(2.8) $n = n_1 + n_2 + \ldots + n_i + \ldots + n_k$,

(2.9) x_i = average, or arithmetic mean, of sample of the i th class,

(2.10) $\bar{x} = w_1x_1 + w_2x_2 + \ldots + w_ix_i + \ldots + w_kx_k$

= estimated mean, or average, of the whole population of size N. Then the total sampling cost for the n observations is

(2.11) $c = n_1c_1 + n_2c_2 + \ldots + n_ic_i + \ldots + n_kc_k.$

Also, if $\sigma_{\bar{x}}$ denotes the standard deviation of $\bar{x}$, then

(2.12) $$\sigma_{\bar{x}}^2 = \frac{w_1^2\sigma_1^2}{n_1} + \frac{w_2^2\sigma_2^2}{n_2} + \frac{w_i^2\sigma_i^2}{n_i} + \ldots + \frac{w_k^2\sigma_k^2}{n_k}$$

It follows that if σ_i, c_i, and w_i are known for each class, or can be approximated satisfactorily, we can choose $n_1, n_2, \ldots, n_k$ so that $\sigma_{\bar{x}}$ will have some specified value, σ_s, at minimum sampling cost, by employing the following formula:

$$(2.13) \qquad n_i = \left(\frac{S}{\sigma_s^2}\right)\left(\frac{w_i \sigma_i}{\sqrt{c_i}}\right),$$

where

$$(2.14) \qquad S = w_1 \sigma_1 \sqrt{c_1} + w_2 \sigma_2 \sqrt{c_2} + \dots + w_i \sigma_i \sqrt{c_i} + \dots + w_k \sigma_k \sqrt{c_k}.$$

Or, if we wish $\sigma_{\bar{x}}$ to be as small as possible where c, the total sampling cost, is to be some specified amount, c_s, we can use

$$(2.15) \qquad n_i = \left(\frac{c_s}{S}\right)\left(\frac{w_i \sigma_i}{\sqrt{c_i}}\right).$$

In defining c_i, the sampling cost per observation for the ith ~~th~~ class, one should usually include not only the cost of selecting the sample observation, but also the cost of inspecting or measuring, the cost of recording, and any other incidental cost one may wish to take into consideration. This cost may be expressed in money, in man-hours, or as a percentage or index number relative to the cost for one particular class. If the sampling cost per observation is about the same for each class, each c_i in formulas (2.13), (2.14), and (2.15) may be replaced by one.

To determine or approximate σ_i, it may be necessary to take and analyze a small pilot sample. The symbol w_i should be regarded as a weight indicating the relative importance of the i th class in the entire population. For example, equation (2.10) may be used to estimate the per cent condition of a physical plant where x_i is the per cent condition of plant belonging to the i th class and w_i is the relative investment in that class.

The cost of stratified sampling should be compared with the cost of unstratified, or simple, sampling. Unless the possible savings is appreciable, it may be better not to stratify so that the sample distribution can be tested as outlined in section 9 of this appendix.

Example 1

		Class of Telephone Service			
	Symbol	Business Individual Line	Residence Individual Line	Residence Party Line	Total
Class	i	1	2	3	
Size of class	N_i	100,000	300,000	600,000	1,000,000
N_i/N	w_i	.1	.3	.6	1.0
Standard deviation	σ_i	\$9.00	\$2.00	\$ .50	

	Symbol	Class of Telephone Service: Business Individual Line	Residence Individual Line	Residence Party Line	Total
Sampling cost	c_i	1	1	1	
Product	$w_i\ \sigma_i\ \sqrt{c_i}$	.9	.6	.3	1.8
Desired value of $\sigma_{\bar{x}}$	σ_s				.02

Computations

$$\frac{S}{\sigma_s^2} = \frac{1.8}{(.02)^2} = 4{,}5000$$

	Check
$n_1 = .9$ of $4{,}500 = 4{,}050$	$(.9)^2 \div 4{,}050 = .000200$
$n_2 = .6$ of $4{,}500 = 2{,}700$	$(.6)^2 \div 2{,}700 = .000133$
$n_3 = .3$ of $4{,}500 = 1{,}350$	$(.3)^2 \div 1{,}350 = .000067$
$n = 8{,}100$	$.000400$

$$\sqrt{.000400} = .02$$

Note: The above data are hypothetical, and should not be interpreted as describing an actual situation.

Example 2

A special case arises when we wish to estimate the proportion of a stratified population that possesses some particular property, and some information is available as to how items possessing this property are likely to be distributed among the various strata. For example, suppose we wish to determine the proportion of telephones that are equipped with visual signals; and that from existing knowledge, it is thought the distribution of these signals between business and residence telephone service is as follows:

	Business Service	Residence Service	Total
Total no. of telephones	500,000	850,000	1,350,000
Estimated no. equipped with visual signals	7,335	765	8,100
Estimated per cent equipped with visual signals	.01465	.00090	.00060

Assume that we wish to select a sample sufficiently large so that the actual per cent equipped with visual signals can be determined with a standard deviation of .0003, or .03 of 1 per cent. Proceeding as in Example 1, we prepare the following table:

	Symbol	Class of Service: Business	Class of Service: Residence	Total
Class	i	1	2	
Size of class	N_i	500,000	850,000	1,350,000
N_i/N	w_i	.3704	.6296	1.0
Standard deviation*	σ_i	.120147	.029986	
Sampling cost	c_i	1	1	
Product	$w_i \sigma_i \sqrt{c_i}$	.04450	.01888	.06338
Desired value of σ_p	σ_s			.0003

*The values of σ_1 and σ_2 are obtained as follows:

$$\sigma_1 = \sqrt{(.01465)\ (1 - .01465)} = .120147,$$

$$\sigma_2 = \sqrt{(.00090\ (1 - .00090)} = .029986.$$

Computations

$$\frac{S}{\sigma_s^2} = \frac{.06338}{(.0003)^2} \quad 704,200$$

Check

$$n_1 = (.04450)(704,200) = 31,350 \qquad (.04450)^2 \div 31,350 = .000\ 000\ 0632$$

$$n_2 = (.01888)(704,200) = 13,300 \qquad (.01888)^2 \div 13,300 = .000\ 000\ 0268$$

$$n = n_1 + n_2 = 44,650 \qquad .000\ 000\ 0900$$

$$\sqrt{.000\ 000\ 0900} = .0003$$

3. COMPUTING THE COEFFICIENT OF VARIATION FROM STRATIFIED SAMPLE DATA

By definition, the coefficient of variation for any statistic is the ratio of its standard deviation to its mean value. It is sometimes useful in problems where the mean value of the population varies from time to time, but the coefficient of variation is known or believed to remain about the same. In the Illinois Bell Telephone Company, it has been used to test samples of customers' local usage. The average amount billed for this usage is known, and can also be computed from the sample data. If the percentage difference between the two averages exceeds three times the coefficient of variation, the sample is suspect.

If

(3.1) μ_i = true mean of the ith class

and

(3.2) $$\mu = w_1\mu_1 + w_2\mu_2 + \dots + w_i\mu_i + \dots + w_k\mu_k,$$

then the coefficient of variation of x, as defined by (2.10) above, is

(3.3) $$V_{\bar{x}} = \frac{\sigma_{\bar{x}}}{\mu}.$$

For large samples, it can be satisfactorily approximated by dividing the estimated value of $\sigma_{\bar{x}}$ by $\bar{x}$. The coefficient of variation of $N\bar{x}$, the computed value of $N\mu$ for the entire population, is the same as $V_{\bar{x}}$.

Suppose $V_{\bar{x}}$ has been computed from sample data for some recent year. Then if the ratio of σ_i to μ_i is stable from year to year, $V_{\bar{x}}$ can be approximated for the current year by using the appropriate values of w_i and n_i. If the coefficient is stable from month to month, and 1/12 of the year's sample is selected each month, the coefficient of variation of $\bar{x}$, as computed from data for t months only, is $V_{\bar{x}}\sqrt{12/t}$, where $V_{\bar{x}}$ is the coefficient for an entire year's sample mean.

Example

i	1	2	3	Total
w_i	.1	.3	.6	1.0
σ_i	$9.00	$2.00	$.50	
n_i	4,050	2,700	1,350	8,100
x_i	$5.50	$1.00	$.25	

Computations

$\dfrac{w_1^2 \sigma_1^2}{n_1}$	=	.000200	$w_1 x_1$	=	.55
$\dfrac{w_2^2 \sigma_2^2}{n_2}$	=	.000133	$w_1 x_2$	=	.30
$\dfrac{w_3^2 \sigma_3^2}{n_3}$	=	.000067	$w_1 x_3$	=	$\underline{.15}$
σ_n^2	=	.000400	$\bar{x}$	=	1.00
σ_n	=	.02			
$V_{\bar{x}}$	=	$.02 \div 1.00 = 2\%$.			

Note: The above data are hypothetical, and should not be interpreted as describing an actual situation.

4. COMPUTING THE STANDARD DEVIATION FROM GROUPED MEASUREMENTS

From a sample consisting of n random observations of x, an unbiased estimate of σ_x^2 can be obtained by employing the formula

$$\hat{\sigma}_x^2 = \frac{n \sum x^2 - (\sum x)^2}{n(n-1)} . \tag{4.1}$$

Since the computed value of $\hat{\sigma}_x^2$ is not affected by increasing or decreasing each x by some constant, the x's may be measured from any convenient origin. When the sample size is larger, however, the computations indicated by this formula will be laborious, and it may therefore be convenient to use the computations outlined below.

Assume the x's are grouped by class intervals so that every x belongs to one and only one interval, and so that the upper limit of each interval coincides with the lower limit of the next higher interval. Also, assume the limits to be so chosen that no x falls exactly on the limit dividing two class intervals. Let

(4.2) i = the width of some class interval (that is, the difference between its lower limit and the lower limit of the next higher class),

(4.3) f = the number of sample x's in the interval,

(4.4) m = the sum of the x's in the interval,

and

(4.5) p = the mid-point of the interval.

Then

$$n = \sum f, \tag{4.6}$$

$$\sum x = \sum m, \tag{4.7}$$

and the sum of the squares can be approximated from the formula,

$$\sum x^2 = 2 \sum mp - \sum fp^2 + \frac{1}{12} \sum fi^2, \tag{4.8}$$

where each summation extends over all observed values of the variable summed. By making the appropriate substituions in (4.1) we can estimate σ_x^2 .

If the x's have been selected from a discrete population in which the x's can have only values spaced at intervals j distance apart from one another, then it is better to substitute $f\ (i^2 - j^2)$ for fi^2 in equation (4.8) above. In this case, the effect of grouping is to change the interval width from j to i. Hence, formula (4.8) may be regarded as a special case of the more general approximation formula,

$$x^2 = \quad mp - \quad fp^2 + \frac{1}{12} \quad f(i^2 - j^2), \tag{4.9}$$

where j is the interval width before grouping into intervals of width i.

For the derivation and a discussion of formula (4.8), see H. L. Jones, "The Use of Grouped Measurements", Journal of the American Statistical Association, vol. 36 (1941), p. 525. For a more general discussion of the estimation of moments from grouped data, see P. S. Dwyer, "Grouping Methods", Annals of Mathematical Statistics, vol. 13 (1942), p. 138.

Example*

Usage range x	Number of customers f	Total messages m	Mid-point p	Class interval i	Extensions mp	Extensions fp^2	Extensions $f(i^2 - 1)$
15-19	4	65	17	5	1,105	1,156	96
20-29	4	105	24.5	10	2,572.5	2,401	396
30-32	30	936	31	3	29,016	28,830	240
33-35	40	1,367	34	3	46,478	46,240	320
36-38	18	658	37	3	24,346	24,346	144
	96	3,131			103,517.5	103,269	1,196

$$\overset{2}{x} = 2(103{,}517.5) - 103{,}269) + \frac{1}{12}\ (1196) = 103{,}865.67$$

* Data are taken from the first article mentioned above, and are used by permission of the editor of the Journal of the American Statistical Association.

5. INTERPOLATING WITH GROUPED MEASUREMENTS

Suppose that sample data to have been grouped by class intervals, and that for some particular interval, the values of i, f, m, and p are defined by (4.2), (4.3), (4.4), and (4.5) in this appendix. Then if the distribution of the sample data (in repeated samples) for the class interval in such that the number of observations between $x - \frac{1}{2}$ and $x + \frac{1}{2}$ can be approximated by a line $a + bx$, we can estimate a and b from the equations

$$b = \frac{12(m - fp)}{i^3}, \tag{5.1}$$

$$a = \frac{f}{i} - bp. \tag{5.2}$$

The number of items in the parent universe between $x - \frac{1}{2}$ and $x + \frac{1}{2}$ will be approximately $A + Bx$, where

$$A = \frac{N}{n} a, \quad B = \frac{N}{n} b, \tag{5.3}$$

and N/n is the ratio of the size of the universe to the sample size.

Let i' and p' be the width and mid-point, respectively, of some subclass interval within the interval $p' - \frac{1}{2}i$ to $p' + \frac{1}{2}i$. Then the number of individuals in the parent population that lies within this subclass interval can be approximated from the formulas

$$F' = i'(A + p'B), \tag{5.4}$$

and the sum of the measurements for these individuals can be approximated by

$$M' = F'p' + \frac{1}{12}B(i')^3. \tag{5.5}$$

For the derivation of the above formulas, see H. L. Jones, "The Use of Grouped Measurements", Journal of the American Statistical Association, vol. 36 (1941), p. 525.

Example

A sample of 1,000 is drawn from a population of 100,000 telephone customers. 100 sample customers use from 81 to 100 message units during the month selected for study. Their total usage was 9,200 messages, or an

average of 92 per sample customer. The problem is to estimate how many customers use from 81 to 90 message units, and to estimate the average monthly usage of these customers.

We have

$$i = 20,\ f = 100,\ M = 9{,}200,\ p = 90.5,$$

$$N = 100{,}000,\quad n = 1{,}000,\quad i' = 10,\quad p' = 85.5.$$

Substituting in equations (5.1) to (5.5), we obtain

$$b = .225, \qquad a = -15.3625$$

$$A = -1536.25 \qquad B = 22.5$$

$$F' = 3875, \qquad M' = 333{,}187.5$$

$$\frac{M'}{F'} = 85.98.$$

Hence, it is estimated that there are 3875 customers using 81 to 90 message units per month, and that their average monthly usage is 85.98.

<u>Check</u>

For customers using 91 to 100 message units per month,

$$i = 10, \qquad p = 95.5,$$

whence, from (5.4) and (5.5),

$$F' = 6125, \qquad M' = 586{,}812.5.$$

We now observe that

$$3875 + 6125 = 10{,}000 = \frac{N}{n}f,$$

and

$$333{,}187.5 + 586{,}812.5 = 920{,}000 = 92\,\frac{N}{n}f.$$

Hence, the computations check.

6. SYSTEMATIC RANDOM SAMPLING

The sampling procedure outlined in this section, suggested by J. W. Tukey, combines some of the advantages of both random and systematic sampling. See W. E. Deming, Some Theory of Sampling, pp. 96.

Suppose it is desired to select a sample of size S from a population of N items numbered 1 to N. Then if

$$S = mn \tag{6.1}$$

where m and n are integers, each larger than 1, we may select m subsamples of size n. In most problems, however, it is better to choose m, the number of subsamples, of some convenient size, say 10. We then find the smallest integer n such that $mn \geq S$, the desired sample size. The size of a particular subsample will then be equal to n if mn divides N exactly; otherwise some subsamples will be of size n and some of size $n + 1$. We now find the largest integer, M, such that

$$M \leq N \div n, \tag{6.2}$$

and call M the "counting interval".

A random choice is made of m numbers (either with or without replacement) from among the numbers 1 to M, inclusive. Designate the numbers a, b, c, ..., after arranging in order of size so that $a \leq b \leq c \leq \ldots$. The first subsample will then consist of the items numbered a, $a + M$, $a + 2M$, ...; the second subsample will consist of the items numbered b, $b + M$, $b + 2M$, ...; and so on.

Let

$$x_i = \text{the mean of the ith subsample,} \tag{6.3}$$

and

$$\bar{x} = \frac{1}{m}(x_1 + x_2 + \ldots + x_m). \tag{6.4}$$

Then $\bar{x}$ is an unbiased estimate of the overall mean of the population if the subsamples are all of the same size, and is approximately unbiased if the difference between the sizes of the largest and smallest subsamples is relatively small.

If the random numbers are selected with replacement (so that it is possible for two or more numbers to be the same), the standard deviation of $\bar{x}$ may be estimated from the formulas

$$(6.5) \qquad \hat{\sigma}_x^2 + \frac{1}{m-1} \sum_{i=1}^{m} (x_i - \bar{x})^2,$$

$$(6.6) \qquad \hat{\sigma}_{\bar{x}}^2 = \frac{\hat{\sigma}_x^2}{m} = \frac{1}{m(m-1)} \sum_{i=1}^{m} (x_i - \bar{x})^2.$$

If the random numbers are sampled without replacement (so that no two numbers can be the same), the standard deviation of x can be estimated from

$$(6.7) \qquad \hat{\sigma}_x^2 = \left(\frac{M-1}{M}\right)\left(\frac{1}{m-1}\right) \sum_{i=1}^{m} (x_i - \bar{x})^2,$$

$$(6.8) \qquad \hat{\sigma}_{\bar{x}}^2 = \left(\frac{M-m}{M-1}\right) \frac{\hat{\sigma}_x^2}{m} = \left(\frac{M-m}{M}\right)\left(\frac{1}{m(m-1)}\right) \sum_{i=1}^{m} (x_i - \bar{x})^2.$$

Formulas (6.5) to (6.8) are perfectly general formulas for computing unbiased estimates of $\sigma_{\bar{x}}^2$ and $\sigma_{\bar{x}}^2$ for random samples from any finite population. For samples from a population of infinite size or from a continuous distribution, formulas (6.5) and (6.6) yield unbiased estimates for both sampling with replacement and sampling without replacement.

Example

A sample of size 1,500 is to be selected from a population of 973,000 poles. This sample is to consist of 10 subsamples corresponding to 10 random starts. We put

$$S = 1{,}500$$
$$N = 973{,}000$$
$$M = 10.$$

Since $S \div m = 1{,}500 \div 10 = 150$, we have

$$n = 150.$$

Also, since $N \div n = 973{,}000 \div 150 = 6{,}486\frac{2}{3}$,

$$M = 6{,}486.$$

Our counting interval, therefore, is 6,486. Deming, however, suggests that counting intervals that are multiples of 2 or 5 be avoided, as populations are frequently encountered where there are periodic variations at intervals of 2, 5, and multiples thereof. A good example is tele-

phone numbers, where numbers ending in even hundreds are frequently associated with customers whose telephone usage is above average. Suppose that in this case, we choose a counting interval of 6,387, which will yield a sample slightly larger than necessary.

After numbering the poles, we turn to a table of random numbers and select ten four-digit numbers, excluding duplicates and numbers larger than 6,387. An excellent table of this kind is the Table of 105,000 Random Decimal Digits published in May, 1949, by the Interstate Commerce Commission, Bureau of Transport Economics and Statistics, Washington, D.C. Suppose the ten random numbers, after arranging in order of size, to be

0131, 0830, 1288, 1603, 2523, 2617, 4746, 5550, 5761, and 6204.

Then the first subsample will consist of poles numbered 131, 6518, 12905, and so on at intervals of 6387. The second subsample will consist of poles numbered 830, 7217, 13604, and so on, again at intervals of 6387. The other eight subsamples will be selected in a similar manner.

After selecting the sample poles, the measurement of the particular property in which we are interested should be taken for each sample pole. Suppose we are sampling per cent condition. Then this percentage (expressed as a number or code) should be recorded for each pole, and the average should be computed for each subsample. Suppose these averages to be 64.01, 64.77, 62.96, 63.41, 67.91, 64.85, 60.92, 68.07, 62.89, and 60.80. Designating these values as $x_1, x_2, \ldots, x_{10}$, we compute

$$\bar{x} = \frac{1}{10} \sum_{i=1}^{10} x_i = 64.06.$$

Ignoring the slight difference in sample sizes, this is the sample mean, and is the estimate of the population mean in which we are interested. We also compute

$$\sum_{i=1}^{10} (x_i - \bar{x})^2 = 55.52.$$

Since duplicates were excluded in selecting the random numbers, the sampling procedure is equivalent to sampling without replacement. We may therefore employ equations (5.7) and (6.8), with M and m taken as 6387 and 10, respectively, to obtain

$$\hat{\sigma}_x^2 = \frac{6386}{6387} \left(\frac{55.52}{9} \right) = 6.17$$

$$\hat{\sigma}_{\bar{x}}^2 = \frac{6377}{6387} \left[\frac{55.52}{(10)(9)} \right] = .616$$

7. CONFIDENCE INTERVALS

Let m be some statistic computed from a random sample of size n for the purpose of estimating some parameter, μ, for the population from which the sample was selected. For example, m might be the sample mean, computed for the purpose of estimating the population mean. Or, m might be the sample standard deviation, computed for the purpose of estimating the standard deviation of the population.

Let μ_1 and μ_2 be two numbers such that, if $\mu = \mu_1$, the probability of obtaining an estimate of μ that is equal to or greater than m is p_1; and let μ_2 be a number such that, if $\mu = \mu_2$, the probability of obtaining an estimate of μ that is equal to or less than m is p_2. Let

$$(7.1) \qquad 0 < 1 - (p_1 + p_2) = P \text{ per cent.}$$

Suppose we were to take repeated samples of size n, and suppose we were to compute m, μ_1, and μ_2 for each sample as indicated above, so that m, μ_1, and μ_2 vary from sample to sample. Also, suppose that after computing each set of m, μ_1, and μ_2, we were to state that μ lies between μ_1 and μ_2. Then our statements would be right P per cent of the time. The interval between μ_1 and μ_2 is therefore called the <u>P per cent confidence interval.</u>

To compute the P per cent confidence interval for the mean of a sample from a population of unknown standard deviation, we first estimate $\hat{\sigma}_{\bar{x}}$ by employing equation (6.6) and taking the square root. We next turn to a table of the t-distribution, and find the value of t corresponding to a tabled probability of (1 - P)%. Using this value of t, we find

$$(7.2) \qquad \mu_1 = \bar{x} - t\,\hat{\sigma}_{\bar{x}}$$

and

$$(7.3) \qquad \mu_2 = \bar{x} + t\,\hat{\sigma}_{\bar{x}} .$$

The required confidence interval is between μ_1 and μ_2.

<u>Example</u>

Suppose we wish to find the 98% confidence interval for the sample mean of the data in the previous example. We have

$$\bar{x} = 64.06.$$

To be conservative, we recompute $\sigma_{\bar{x}}^2$ from equation (6.6), obtaining

$$\sigma_{\bar{x}}^2 = \frac{55.52}{90} = .617.$$

We also determine

$$(1 - P)\% = 1 - .98 = .02.$$

Entering a table of the t-distribution on the line corresponding to 10 - 1, or 9, degrees of freedom, we find the number 2.821 as the value of t corresponding to a probability of .02. (This means that numerical, or absolute, values of t greater than 2.821 occur only 2 per cent of the time). In other words, values of t algebraicly greater than 2.821 occur 1 per cent of the time, and values of t algebraicly less than - 2.821 occur 1 per cent of time. Suppose we put

$$\mu_1 = 64.06 - 2.821\ (.617) = 62.32,$$

and

$$\mu_2 = 64.06 + 2.821\ (.617) = 65.80.$$

Then we can say that the mean of the population sampled lies between 62.32 and 65.80 with a 98% chance of being right.

8. ANALYSIS OF VARIANCE

Suppose that sample units of property have been inspected by m crews of men to determine its overall average per cent condition. Then if the assignment of units to crews is random, and if the systematic random sampling procedure outlined in section 6 of this appendix is used, we could use the analysis of variance to determine whether the variations between crews in the conditions reported was excessive or not.

Let x_{ij} denote the average per cent condition of all the sample units in the jth sample that were inspected by the ith crew. We arrange the x's as shown in the table below, and make the computations indicated.

Crew	Subsample 1	2	...	n	Crew total	Crew mean
1	x_{11}	x_{12}	...	x_{1n}	$\sum x_{1j}$	x_{10}
2	x_{21}	x_{22}	...	x_{2n}	$\sum x_{2j}$	x_{20}
...	...	...	...	...	...	...
m	x_{m1}	x_{m2}	...	x_{mn}	$\sum x_{mj}$	x_{m0}
Subsample total	$\sum x_{i1}$	$\sum x_{i2}$	...	$\sum x_{in}$	$\sum\sum x_{ij}$	
Subsample mean	x_{01}	x_{02}	...	x_{0n}		

(8.1) $$\text{Subsample mean} = \frac{1}{m} \sum_{i=1}^{m} x_{ij} = x_{0j}.$$

(8.2) $$\text{Crew mean} = \frac{1}{n} \sum_{j=1}^{n} x_{ij} = x_{i0}.$$

(8.3) $$\text{Sample mean} = \frac{1}{n} \sum_{j=1}^{n} x_{0j} = \frac{1}{m} \sum_{i=1}^{m} x_{i0} = \bar{x}.$$

		Component	Sum of squares	Degrees of freedom
(8.4)	A.	Total variance	$\sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij} - \bar{x})^2$	mn - 1
(8.5)	B.	Variance between crews	$n \sum_{i=1}^{m} (x_{i0} - \bar{x})^2$	m - 1
(8.6)	C.	Variance within crews	A - C	m(n - 1)
(8.7)	D.	Variance between subsamples	$m \sum_{j=1}^{n} (x_{0j} - x)^2$	n - 1
(8.8)	E.	Residual variance	C - D	(m - 1)(n - 1)

(8.9) $$F = \frac{\text{Variance between crews}}{\text{Variance within crews}} .$$

Example

Subsample	Crew 1	2	3	4	5	6	7	8	Average
1	58.9	58.5	62.9	50.5	57.1	63.3	55.5	80.7	60.92
2	67.3	59.9	62.9	63.5	64.0	56.1	75.5	53.9	62.89
3	58.1	82.1	60.3	54.1	62.4	72.6	66.9	61.7	64.77
4	73.3	77.1	58.3	62.6	65.6	73.8	68.0	65.9	68.07
5	55.1	57.2	73.3	68.1	65.1	71.8	57.5	59.2	63.41
6	63.0	62.5	59.1	68.9	77.1	63.4	59.4	65.4	64.85
7	61.0	59.8	63.0	56.7	60.3	74.7	66.4	61.8	62.96
8	59.8	57.7	57.2	58.8	78.7	54.1	59.3	60.8	60.80
9	61.2	57.8	67.8	57.6	65.8	61.3	57.3	83.3	64.01
10	77.7	59.2	66.8	73.2	70.4	66.4	67.0	62.6	67.91
Average	63.54	63.18	63.16	61.40	66.65	65.75	63.28	65.53	64.06

Component	Sum of squares	Degrees of freedom	Variance of x
Total variance	4129.27	79	52.27
Variance between crews	212.64	7	30.38
Variance within crews	3916.63	72	54.40
Variance between subsamples	444.43	9	49.38
Residual variance	3472.20	63	55.11

$$\text{Variance ratio} = \frac{30.38}{54.40} = .56$$

Since the variance ratio tends to be in the neighborhood of one when the differences between crews is due to chance alone, and greater when these are other causes of difference, the observed ratio would indicate that the differences are not excessive. Even differences as large as 2 would not seem surprising. In problems of this kind, one should not bother to assign a probability to the ratio (that is, the probability of having a ratio as large as the one observed if only chance causes were operating), since it is already known that there is an assignable cause of differences.

9. CHI-SQUARE TEST OF GOODNESS OF FIT

The following test is useful to see whether the distribution of sample items among several classes differs from the known distribution of the population among these classes to a greater extent than one would expect if the difference was solely due to chance. Some such test should always be made when it is possible to do so.

Suppose that a population consists of the classes A, B, ..., K in the known proportions $p_1, p_2, \ldots, p_k$, respectively, so that

$$p_1 + p_2 + \ldots + p_k = 1. \tag{9.1}$$

Then in a sample of size n, we should expect the sample frequencies for the various classes to be approximately

$$p_1 n,\ p_2 n,\ \ldots,\ p_k n. \tag{9.2}$$

Suppose the actual sample frequencies for these classes to be

$$f_1,\ f_2,\ \ldots,\ f_k, \tag{9.3}$$

so that

$$f_1 + f_2 + \ldots + f_k = n. \tag{9.4}$$

Then we can test the sample distribution to see whether it is unusual or not by computing

$$\chi^2 = \frac{(f_1 - p_1 n)^2}{p_1 n} + \frac{(f_2 - p_2 n)^2}{p_2 n} + \ldots + \frac{(f_k - p_k n)^2}{p_k n}, \tag{9.5}$$

and compare with tabled values of χ^2 for k - 1 degrees of freedom.

Example

A sample of 339 manholes was inspected to determine the per cent condition of underground plant. Among these sample manholes, 136 were of type A, 94 of type B, 46 of type X, and 63 of other types. From plant records, it is known that the sample was selected from a total in which 38.2% were of type A, 27.8% of type B, 15.4% of type X, and 18.6% of other types. The problem is to determine whether the sample distribution was unusual.

The computations are as follows:

Type	p	pn	f	$(f - pn)^2$	$(f - pn)^2/pn$
A	.382	129.5	136	42.25	.326
B	.278	94.2	94	.04	.001
X	.154	52.2	46	38.44	.736
All other	.186	63.1	63	.01	.000
Total	1.000	339	339		1.063

$$\chi^2 = 1.063$$

$$k - 1 = 3$$

Turning to a table of χ^2 for 3 degrees of freedom, we see that the entry corresponding to n = 3 and P = .80 is 1.005. Hence, samples with values of χ^2 as large as the sample actually taken would be expected to occur almost 80 per cent of the time. We therefore conclude that the difference between the sample frequencies and the expected frequencies are not unusual, and that so far as this test is concerned, there is nothing to indicate that the sampling procedure is not satisfactory.

10. TABLE OF AUDITOR'S RISKS

The following table shows the risk of not detecting at least one of 1, 2, ..., 8 discrepancies in a cashier's accounts if a random sample is taken covering 2, 4, ..., 20 per cent of the total of a large number of accounts of one or more cashiers. Thus, the last entry in the column headed "1" means that if there is just one discrepancy in all the accounts, a 20 per cent sample selected at random will have 80 chances out of 100 of not including that particular discrepancy.

If the sample is not selected at random, but is selected by taking a whole tray of address plates here and there, for example, the risks may be different from those shown in the table for more than two discrepancies, unless these discrepancies themselves are distributed in a random fashion.

Sample	Number of Discrepancies							
Per Cent	1	2	3	4	5	6	7	8
2%	.98	.96	.94	.92	.90	.89	.87	.85
4	.96	.92	.88	.85	.82	.78	.75	.72
6	.94	.88	.83	.78	.73	.69	.65	.61
8	.92	.85	.78	.72	.66	.61	.56	.51
10	.90	.81	.73	.66	.59	.53	.48	.43
12	.88	.77	.68	.60	.53	.46	.41	.36
14	.86	.74	.64	.55	.47	.40	.35	.30
16	.84	.71	.59	.50	.42	.35	.30	.25
18	.82	.67	.55	.45	.37	.30	.25	.20
20	.80	.64	.51	.41	.33	.26	.21	.17

The formula for computing the above table is simply

$$R = (1 - P)^d \qquad (10.1)$$

where P is the sample percentage (expressed as a fraction), d is the number of discrepancies, and R is the risk of not detecting at least one of the discrepancies present.

11. CONTROL LIMITS FOR P-CHARTS WHEN THE SAMPLES VARY IN SIZE

In establishing and maintaining p-charts for samples that vary in size, one of the difficulties is the labor of computing the control limits. When p is sufficiently small, however, so that the equation

(11.1) $$\sigma_{\bar{p}} = \sqrt{\bar{p}/n}$$

is approximately correct, considerable simplification is possible. (Compare Paul Peach, "An Introduction to Industrial Statistics and Quality Control", 1947, page 63.)

Suppose that $\bar{p}$ has been computed from sample data by dividing the observed total number of defective units by the total number of units inspected. We first find the reciprocal, $1/\bar{p}$ and multiply this value by each of the values shown in the columns headed U and L in Table 1. The products are entered in a table like Table 2, which has been constructed to illustrate the case where $\bar{p}$ = .00006. In other words,

(11.2) $$n_u = U(\frac{1}{\bar{p}})$$

and

(11.3) $$n_l = L(\frac{1}{\bar{p}}).$$

TABLE 1

Values of U and L corresponding to various values of c

c	U	L
0	.00000	9.00000
1	.09167	10.90833
2	.31534	12.68466
3	..62614	14.37386
4	1.00000	16.00000
5	1.42225	17.57775
6	1.88316	19.11684
7	2.37586	20.62414
8	2.89531	22.10469
9	3.43769	23.56231
10	4.00000	25.00000
11	4.57984	26.42016
12	5.17525	27.82475
13	5.78463	29.21537
14	6.40661	30.59339
15	7.04006	31.95994

TABLE 2

Values of n_u and n_l corresponding to various values of c

$\bar{p} = .00006$

c	n_u	n_l
0	0	150,000
1	1,528	181,806
2	5,256	211,411
3	10,436	239,564
4	16,667	266,667
5	23,704	292,963
6	31,386	318,614
7	39,598	343,736
8	48,255	368,412
9	57,295	392,705
10	66,667	416,667

For a discussion of these tables, see <u>Industrial Quality Control</u> for September 1951, pp. 26-27.

12. FORMULAS FOR SEQUENTIAL SAMPLING OF ATTRIBUTES

Suppose that random selections from an infinite lot are inspected one at a time, the inspection continuing as long as

$$ns - h_1 < d < ns + h_2 \tag{12.1}$$

where n is the number of items inspected, d is the number of defective items, and h_1, h_2, and s are positive constants such that $h_1 + h_2 \geq 2$ and $0 < s < 1$. Let p denote the fraction defective in the lot. Then if p is reasonably small, the probability of acceptance and the average amount of inspection can be approximated by the following procedure:

Choose convenient values of a variable x; for example, let x = .1, .2, .5, 1.0, 2.0, 5.0, and 10.0. For each value of x, compute

$$p = \frac{x^s - 1}{x - 1}, \tag{12.2}$$

$$L_p = \frac{x^{h_1+h_2+a} - x^{h_1}}{x^{h_1+h_2+a} - 1}, \tag{12.3}$$

$$\bar{n}_p = \frac{L_p(h_1+h_2+cq) - (h_2+cq)}{s - p} \tag{12.4}$$

where

$$a = \frac{1}{3}(1 - 2s) \tag{12.5}$$

$$c = a/(1 - s). \tag{12.6}$$

$$q = 1 - p. \tag{12.7}$$

Then for the values of p computed from formula (12.2), the probability of acceptance can be determined approximately from formula (12.3). The average amount of inspection can be approximated from formula (12.4).

These formulas are modifications of those given by Statistical Research Group, Columbia University, in Sequential Analysis of Statistical Data: Applications (1945). For a discussion, see H. L. Jones' article in the Annals of Mathematical Statistics for March, 1952.

To design a sampling plan such that for $p = p_1, p_2$, the probability of acceptance will be $L_{p_1} = 1 - \alpha$, $L_{p_2} = \beta$, we compute

$$s = \log (q_1/q_2)/\log (p_2q_1/p_2q_2), \tag{12.8}$$

$$h_1 = \log \left[(1 - \alpha)/\beta\right] /\log (p_2q_1/p_1q_2), \tag{12.9}$$

$$h_2 = \log \left[(1 - \beta)/\alpha\right] /\log (p_2q_1/p_1q_2) - \tfrac{1}{3} (1 - 2s). \tag{12.10}$$

VENDOR CERTIFICATION

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Vendor-consumer relations, the good will existing between the buyer and seller of a product, are dependent on a large number of intangibles. It is not proposed to discuss in this paper all of the intangibles that tend to build up the desired friendly relations, but it is proposed to consider a program to minimize and possibly eliminate some of the factors which, most frequently, adversely affect the amicable relations.

My presence on this program is as a member of the Electronics Technical Committee of the American Society for Quality Control, and not as an authorized representative of the Bureau of Ordnance. The opinions expressed are, therefore, the views of the Electronics Technical Committee or my own personal ones, and do not, except as otherwise indicated, necessarily represent the opinions and policies of the Navy Department and the Bureau of Ordnance.

Probably the most important, and certainly the most concrete, of the factors affecting vendor-consumer relations is a difference of opinion of the quality of the product. It must be assumed that any difference of opinion is due to a difference of interpretation of the specifications, drawings, standards, or requirements of the purchase order by which the consumer has indicated he wishes to purchase the product of the seller.

In most instances, the evaluation of the quality of the product as received is based on an independent interpretation of the specified requirements, and frequently the material is rejected and scrapped, returned to the vendor, or reworked by the consumer on the basis of this difference in interpretations. The outgoing inspection of the vendor has satisfied him that the product meets the vendor's standards; the incoming inspection of the consumer has satisfied him that it is not up to the standard that the consumer wishes to put in his product. Both are honest in their evaluation but different in the interpretation.

In addition, the duplication of the inspection operation, with its possible additional screening or rework requirements adds a cost to the finished product which is unnecessary and desirably might be eliminated. This elimination could occur only if the consumer were familiar with the inspection standards of the vendor, if the process average of the vendor was satisfactory to the consumer, and if the consumer was satisfied with the criteria to which the outgoing product was inspected prior to the shipment from the plant of the vendor.

Much could be accomplished toward this elimination of extra operations by the introduction of a standard criterion of quality. The introduction of such a standard, with a free exchange of information between producer and consumer, would result in increased confidence between seller and buyer, and consequently a drastic reduction of inspection costs if mutually acceptable standards were adopted.

The Electronics Technical Committee of the American Society for Quality Control, for some time, has been studying the introduction of a standard criterion of quality based on a mutually acceptable, but written, interpretation of the specification requirements and including a determination of the seriousness of certain defects. It was hoped that the adoption of

such a standard would permit the elimination of receiving inspection by the consumer without reduction of assurance of quality in the end product upon appropriate certification by the vendor of conformance to the standard.

The Electronics Technical Committee became initially interested because of the nature of the electronics industry. The fundamental components of the entire industry are largely composed of standard items such as resistors, capacitors, transformers, tube sockets and tubes, and a large number of these standard components are used by a great variety of consumers throughout the industry.

To permit the greatest utilization throughout the industry, the proposed standard would have to be acceptable to both the vendor and the consumer. Free exchange of information on process averages, including observed defects, must be anticipated.

The question has been well-raised as to who should undertake the introduction of such a standard. Certain associations of manufacturers have a wide interest in the field. Technical societies of various categories cover the field of a large number of products and manufacturers, and in general are less sensitive to industrial pride and prestige with its barriers to full understanding and open support of a nation-wide program. The American Society for Quality Control, in the position of a technical society, is even less restricted by normal trade barriers since the membership represents a greater cross section of industry, and of management and operation, than most technical societies.

The Committee has been advised by counsel that no infringement of existing laws was apparent in this activity and that we were within the scope of the Constitution and Charter of the American Society for Quality Control.

In the belief that it was essential that the industry as a whole participate in any plan to establish a uniform criterion of quality, a letter and questionnaire was sent out in the fall of 1951 to a randomly selected sample of the electronics industry. This letter briefly outlined the plan presented in this paper and the questionnaire was designed to determine the interests of the addressees in the program. Points covered were:

a. Buyer or seller
b. Type of components
c. Reaction to proposal
d. Participation
e. Name of individual to represent company

The response to the questionnaire was quite favorable. It is of interest to note that the return of questionnaires was approximately 22% as compared with the usually expected rate of return between 5% and 10%. 84% of the replies were favorable, 3% unfavorable and 13% undecided, no longer in business, or for some other reason unable to participate.

The Committee has also been advised informally that the questionnaire has been the subject of extensive discussion in various portions of the industry, including even those manufacturers who did not return the questionnaire. It is reported that these discussions were, in general, favorable.

As the next step in the program, representatives of the manufacturers

and industries replying to the questionnaire, along with representatives of trade associations which exhibited an interest in the proposed program, were invited to meet in New York in March for a mutual consideration of the implementation of a plan for a standard criterion of quality on a limited basis.

The Committee and its technical advisers have considered that the minimum elements of an acceptable standard which must be established before the plan can be introduced, even on a limited and trial-run basis, are:

a. A classification of defects
b. The use of a recognized sampling plan
c. An acceptable quality level (AQL)
d. A lotting plan adaptable to sampling techniques
e. Process average information at the producer's plant

The classification of defects will of necessity be sufficiently broad to cover a large portion of the uses of a particular component within the industry. It is not foreseen that all characteristics which might be defective can be listed, since the use of this component in certain equipments may stress the importance of a characteristic which is relatively unimportant in the more normal uses of the component. The classification of defects is, therefore, important to advise the consumer of those characteristics which have been inspected by the manufacturer, and to permit the consumer to devise an acceptance inspection plan for those characteristics deemed peculiar to his product. It has been estimated that approximately 95% of the uses and applications of resistors, for example, could be covered by a general classification of defects. The balance of the industry could be covered by the listing of a few additional characteristics or a minor number of changes in the classification, and these additions or changes might be accomplished by the terms of the purchase order. In any event, the incoming inspection of the consumer could be restricted to examination of the shipment for those characteristics which were peculiar to the end product of the consumer. The vendor would certify that such a classification of defects had been used.

Even if the consumer were not willing to forego all incoming inspection, both the vendor and consumer would be using the same criteria for inspection as listed in the classification of defects. Certainly no ill effect on vendor-consumer relations can be expected if the same standard is used by both. A normal result of such duplicate inspection, where the certification of the vendor is confirmed by the findings of the consumer, is a reduction in the amount of the consumer incoming inspection.

The utilization of a recognized sampling plan approaches a more controversial phase of the plan. Some manufacturers use the Dodge-Romig sampling plans. Others prefer MIL-STD-105A because of its wide use by the armed forces. The RTMA has prepared and is considering the adoption of another set of sampling tables. Since all of these sampling tables achieve an end result which is identical, the different sampling tables in use do not appear to present an insurmountable difficulty and in some instances, the different tables have been considered as only a minor factor. The vendor certification should, however, include for the information of all, a statement of which table was used.

The heart of the entire matter is the acceptable quality level or fraction defective on which the sampling plan is based and to which the

vendor is willing to certify that his product conforms. All of us recognize that no sold product and no bought product is 100% perfect. Hence, we have outgoing inspection and incoming inspection. Those of us who have had experience with 100% inspection under these two conditions recognize that such inspection is approximately 85% efficient. We have, therefore, accepted a calculated risk of a certain percentage of defectives and an AQL for a product merely places on the record the recognition of this calculated risk. Sampling plans, allowing a known fraction defective to pass, are surprisingly, in some instances, more stringent in their limitations of risk than less formal inspection plans, including 100% inspection. The vendor's certification should be all means include a statement of the AQL to which the product conforms.

Some variation in the Acceptable Quality Level is foreseen. For example, military products may require a higher quality level than routine commercial products. Exceptionally high quality levels could be the basis for a price differential.

The lotting plan is not a part of the proposed vendor certificate, but is an underlying condition which must be present in the contractor's plant to permit the use of sampling techniques. Lot sizes for acceptance sampling may be based on a day's production, a given number of units, or any other criterion which meets the requirement of homogenous production. The lotting plan may, of necessity, have to vary not only with the component but also with the various manufacturers of the same component.

Process average information, either in the form of a statement of fact, a control chart, or a histogram, will be necessary for the consumer to evaluate adequately the calculated risk inherent in the sampling plan. Any published information on the use of operating characteristics for sampling plans makes it obvious that the risk of accepting a single lot is too great to ask that a consumer assume such a risk. Coupled, however, with process average information, this risk is greatly reduced, and is small enough to be acceptable.

Those of you who are familiar with sampling techniques will agree that, with the five pieces of information mentioned, it would be a simple matter to evaluate the risk of accepting a shipment of material without incoming inspection, or to plan a greatly reduced inspection if the material was not entirely in accord with some special requirements. If full incoming inspection is still considered desirable, the reduction of the area of disagreement between vendor and consumer is drastic if the standard and the vendor's certification provide a common basis for the consumer's evaluation.

What then are the obstacles to the introduction of such a plan? The size of the task is an appreciable one - fortunately it can be implemented bit by bit. It is envisaged that each separate classification of defects will be a form of standard. When drawn up and approved by the major portion of a segment of industry, it can be filed with the Standards group or with ASTM as an approved standard, and each manufacturer within that segment of industry can begin its use.

Duplication of efforts of other groups will effectively hinder the implementation of such a program. The Electronics Technical Committee of the ASQC has invited the participation of every interested group in the promulgation of this plan. It is not believed that there is currently any duplication of the efforts of another group, and it is hoped that the inter-

locking membership of some of the technical committees will prevent its recurrence.

Occasionally the fear is expressed that punitive or police action will be an integral part of such a plan. There is no more need to fear this approach than is currently in effect in certain other products. The Committee and the Society consider that the service we can render consists of proposing the standard for adoption after it has been developed by the industry. There are no police actions required to enforce a standard if it is necessary and this standard of quality is just as necessary for the further simplification of some of our industrial problems as other adopted standards now in use.

CERTIFICATION OF QUALITY

THE PRODUCT SHIPPED HEREWITH HAS BEEN INSPECTED AND ACCEPTED IN ACCORDANCE WITH THE FOLLOWING REQUIREMENTS:

PRODUCT ________ (NUMBER) ________ (NAME) ________ (SPECIFICATION)

ASQC STANDARD ________ LOT SIZE ________ SAMPLE SIZE ________

SAMPLING PLAN USED ________ AQL ________

DEFECTS OBSERVED IN SAMPLE: (SHOW DEFECT AND RATE OF OCCURRENCE)

	CRITICAL	MAJOR	MINOR
	0	#101 2 #113 4	#201 5 #204 3 #207 2
PROCESS AVERAGE (FOR LAST 10 LOTS)	____ %	____ %	____ %

________ DATE ________ CHIEF INSPECTOR

FIGURE 1
Sample Certification Form

Figure 1 is a suggested form incorporating the required information on a certificate by the vendor or producer of a product. Those of you who are quality engineers realize the adequacy of this information to simplify some of your most pressing problems.

Various committees can be established to assist you or your segment of industry in working out the standards applicable to the fields in which you are interested. It, however, is distinctly up to you as representatives of that particular segment to take the initiative and to participate in the formation for a standard criterion of quality for your use. Two such groups were formed as sub-committees at the March meeting in New York - one for composition resistors and one for small fixed condensers. (It is hoped that some report of progress will be available at the time of presentation of this paper).

Allow me for a moment to revert to my status as a representative of the Bureau of Ordnance. The proposed plan for the introduction of a standard criterion of quality has been considered in the Bureau, and the Bureau is willing to consider revision of existing techniques of Ordnance Inspection to the extent warranted by an appraisal of the ultimate form of the plan as implemented. As outlined herein, the Bureau of Ordnance is willing to accept the classification of defects as a fundamental standard and to base its acceptance inspection on that standard, with such modifications, (expected to be minor) which the requirements of Ordnance material may necessitate. Sampling plans have, for some time, been a recognized inspection technique of the Bureau of Ordnance, and our inspection would be based on MIL-STD-105A. Acceptable quality levels have already been established for normal inspection.

QUALITY CONTROL TECHNIQUES FOR ELECTRONIC COMPONENTS

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The wide-spread demand for electronic equipment in the last few years has resulted in a mushroom growth of a large number of both new and old firms. Small companies were hastily formed to supply this demand when it was found that many concerns would have to reduce their production due to electronic shortages caused by defense needs. Those able to obtain financial sponsors have spread their skills over a myriad of electronic components. New techniques sponsored by quality control have played an important role in these developments. However, in many plants the role of quality control has been very minor due to a lack of understanding of its objectives.

The term "Quality Control" has been used to cover a wide variety of activities, many related only indirectly with quality. This is to be expected since the government has demanded that satisfactory and adequate Quality Control Systems be installed in all plants from which the various agencies purchase materiel. Quality Control groups have sprung up in different spots in manufacturing organizations with widely different functions. Some assist engineering and developmental departments in their qualification tests and product engineering activities. Others merely inspect, take little or no data, and wonder why they generate vast quantities of paper work but do not improve the quality of outgoing product. A clearer understanding of the objectives will indicate why the application of certain techniques results in improved outgoing quality at a reduced cost.

The more complicated electronics equipment is often sold as a system. Each system consists of a large number of units. These units are made up from assemblies and sub-assemblies. So-called spares consist of a group of units generally and are often given a final test using sufficient units to make up a system as the test equipment equivalent. The excess units are then removed so that only such units as are required are combined to make up the desired spare. The set-up is similar to switchboards, where a completed board may be fully or partially equipped. Many of the techniques used on switchboards apply equally well to other types of electronic equipment.

In the manufacture of such electronic equipment, quality must be built into the product all along the line. Eternal vigilance is required to see that even minor items of workmanship, which later may be hidden in the maze of wiring and apparatus, are of a satisfactory nature in line with standards of good workmanship. Manufacturing is responsible for the quality of the equipment produced. It provides testers and checkers wherever it is felt that a check must be made in order to prevent the addition of a large amount of costly work to a sub-assembly or component when a small amount of inspection and test effort will prevent substandard parts from being used. Such controls may be thought of as functional controls. When manufacturing, at each production sequence, feels that the component under consideration is unsatisfactory it is turned back for re-work and change by the manufacturing section. Quality Control groups, divisional and central, work co-operatively with manufacturing to assist it to control each step of the process with minimum cost.

Errors in measurements may creep in unless Quality Control applies controls that assure proper calibrations of all test apparatus and testing equipment. Quality Control must analyse all inspection and test results that have meaning and make such auxiliary inspections and tests as may be required for verifying manufacturing's inspection results.

It is impossible in this limited time to describe all the steps and techniques that should be applied in manufacturing the best possible electronic equipment. A few concrete cases will indicate the measures that are necessary. These may be modified in other plants in line with the peculiar needs of each particular manufacturer. Also, recognition must be given to the role that Quality Control must play in the original design, qualification tests, type tests, trials, and ultimately in the manufacturing process itself.

When an objective has been set and engineers and research men are requested to make a new product, it first appears that the job is one that should be confined to the research and design engineers. This is a mistaken notion which will hamper future production and slow down the program. When the research engineer has a new idea to check, it is necessary that he not only check his theoretical concepts with able mathematicians and physicists but also that he check the ability to reproduce the unit and associated data under production conditions. A tailor-made product is a work of art and those connected with its development are unhappy when they find that it cannot be made practicably with the same fine care that the research and development engineers apply in their studies. Drawing board models are extremely valuable. Checks made on prototypes indicate the nature of the discrepancies and what corrective action is required. Here is where the most careful use should be made of the various theories of small lot sizes and samples. The data are meager but rich in potential possibilities. The research and development engineers should discuss their early problems with qualified personnel in the Quality Control groups. Steps should be taken to have the required data obtained according to a prescribed design, such as a Latin Square, and a Factorial Design. When the data are secured, the statistician assists the engineer in the analysis so that all the information contained therein may be summarized. From such information it will be possible to establish a design that is practical and also to set tolerances that can be met in production.

After the design has been initially established, the next step is to set up qualification tests for the product as a whole. The requirements of service may be severe requiring the product to function properly over a wide range of temperatures, high humidity and shock. The necessary tests must next be set up. It is not enough to have the specification spell out the objectives. These must now be set forth in a Test Specification. This test specification must indicate all the tests that are needed in order to insure that the equipment will function properly alone or as a part of a larger unit. In this connection it may be necessary to set up regular periodic tests to determine that in subsequent manufacturing the product will continue to be satisfactory. The amount of testing required appears at first to be purely an engineering problem. However, it is again desirable for the team consisting of the Development Engineer and the Quality Control Engineer to collaborate and write out explicitly how much information is required periodically. With this

information a complete testing program can then be set up. The number and nature of the tests must be tabulated and at times even incorporated in the specification or contract. Some tests will require very expensive testing equipment. Also, some tests may be destructive in nature and require extra units to be taken from the line at random as representative of the process. When set up properly, suitable controls will be established so that it can readily be determined whether the process remains in statistical control.

These techniques precede the regular production runs, although the type test may be run in conjunction with production as time goes on to maintain continued control. Pilot runs are highly desirable. In many instances, due to an immediate demand for the product, the pilot run phase of the operation is dropped. This is unfortunate as it precludes the elimination of a lot of undesirable features that arise in production when it is found that the design which was satisfactory for research and development purposes cannot be made in quantity. Hence slight changes in the design must be made to permit continuous production at a reasonable rate.

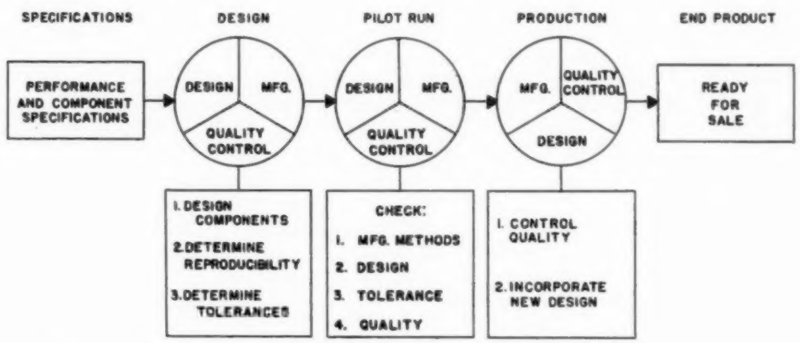

FIG. 1 QUALITY CONTROL IN PRODUCTION

Two other factors need to be considered: (1) Life and (2) Ease of Maintenance. I was originally asked to discuss Life Tests on vacuum tubes but preferred to cover the broader aspects of the entire problem rather than to discuss particular techniques covering Life Tests on only one electronic component. While the product is being qualified, it will be necessary to have some units on Life Test. If enough information is available, such Life Tests may in many cases, be accelerated. This is highly desirable as it indicates early in the production process the inherent weakness in the product resulting from design or the particular manufacturing process. In many instances, however, there has been found no accelerated substitute for the normal Life Test under standard operating conditions.

Consider the nature of the Life Test data required for a vacuum tube. First, a sufficient sample must be taken, say 25, so that the final results of the Life Test will provide both an indication of level, or central tendency, and an indication of spread or variability. For the key characteristics for a particular type tube, readings must be taken

at sufficient time intervals to provide a fairly accurate picture as to what may happen. In some instances the development engineer must know the increase in variability that results from having intermittent operation rather than continuous operation. Preferably, a form should be provided to record the readings at the intervals desired. In this connection it is well to consider the working hours of the technicians making the readings so that the observations will be obtained during regular working hours.

The distribution for many types of vacuum tubes is essentially bi-modal with respect to life. It has been found that the early failures are usually due to mechanical difficulties whereas the failures that occur later are primarily electrical. In order to obtain a true picture for any given type, a preliminary run should be made to indicate how frequently readings should be taken in order to obtain this bi-modal curve, particularly in the early part of the test. If readings are not obtained at short enough intervals, unless an automatic recorder has been used, the exact time of the early failures will not be known. With some of the more stable tubes the time interval between readings may be very long. This is true if the expected life of the particular tube type is 5,000 hours or more. If, however, the expected life is 500 hours or less, readings will have to be taken much more frequently. Vacuum tubes have to be tested under standard operating conditions, as, so far, no real means that has any meaning has been obtained for accelerating their life. With capacitors, on the other hand, accelerated life tests may be used with a reasonable degree of success.

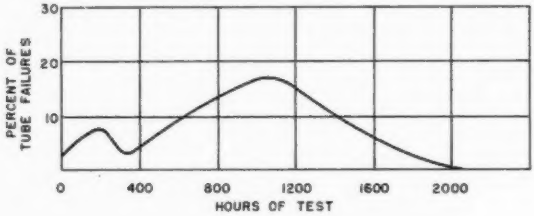

FIG. 2 VACUUM TUBE LIFE EXPECTANCY

The problem next arises - How can one determine from the early readings and failures whether the lot of tubes from which the sample was taken is satisfactory for release for shipment? A life test is being run with, say, 25 tubes on life test. The expected life is 800 hours. After 200 hours on test, 3 of the tubes have failed. Should the lot be accepted, rejected or be suspended until additional data on these 25 tubes has been obtained? Several papers on this subject have been published (1). None of them give the exact solution, but they do assist one in formulating the problem.

In all kinds of tests that require a long time to make, such as many environmental tests, the question arises, "How long shall a lot be held before release?" Until the tests are completed? This is the most desirable, but that may mean at least 1 month or possibly 6 months.

The problem of storage space confronts all manufacturers if all units are to be held until these long tests are completed. It is not unusual to require 100 hour tests. Now a month of 30 days contains only 720 hours so that a 1000 hour test means about 1-1/2 months holding period. To many it appears reasonable to release the lot for shipment if no failures occur in the first 48 hours and the readings are satisfactory. What risks are being taken? The answers to such questions require prior analysis of comparable data. Since such data are not usually available in large quantities in a single company, the pooling of such information by associations representing large numbers of manufacturers, such as the Radio-Television Manufacturers Association (RTMA), is highly desirable.

The majority of the tests, or at least inspections for dimensions, color, appearance, materials and workmanship, are done by attributes inspections. One of the techniques that is often important is to properly classify the items being checked as to their importance. This leads to a weighted value, often expressed in terms of Demerits or Demerits-per-Unit. If this procedure is to be followed, then a Classification of Defects is required. Possibly the better term is a Classification of Inspection Items with respect to their importance in line with certain clear-cut definitions as to the method used in the classification. Four-fold classifications are the most popular. Often such a classification results in essentially a three-fold or sometimes even only 1 classification. The Military use the terms: (1) Critical, (2) Major, (3) Minor, and (4) Incidental. Using the published definitions (2), it is possible to properly evaluate all the requirements with respect to their importance.

There are some that oppose any classification of defects. Their argument is that all requirements must be satisfied. If even an Incidental Inspection Item is not met, then steps should be taken to eliminate this situation and each inspection item should be considered equally important. Analyzing each item, its application and function in accordance with its specification and specifically per the appropriate drawing, then a conclusion may be reached as to the advisability of using a weighting system. Many articles on Rating (3) cover this point to a degree. More research is required on this subject in order to properly evaluate it. The use of weighting values should be carefully considered. Where many components enter a final rate, use may be made of the notion of using weights based on experience, demand, maintenance costs or even initial costs. There are many border line cases where fraction defective is not too good a measure of quality. Careful judgment is required to incorporate the proper system in any well organized Quality Control program.

The Quality Control engineer should assist the design engineer in determining over-all tolerances. At first this appears to be an easy task, from the manufacturing point of view, where it is possible to obtain large quantities of data upon which the tolerances may be based. The design engineer readily determines from theoretical considerations whether the tolerances arrived at from the data are reasonable. Often, however, the theoretical design demands a very rigid tolerance which cannot possibly be met. If this is the case, then it is necessary to study the distributions of the various components and determine the contribution of each to the over-all variability. Where the distribution is essentially linear, then it is possible to arrive at a quick solution based on a random distribution. Adding the variances of the components may provide a fairly

close estimate of the over-all variance under the above conditions. Squaring the component tolerances and adding them gives a theoretical value for the square of the over-all tolerance. This procedure is based on the theorem concerning the addition of variances where the variance is the standard deviation, σ, squared, and the standard deviation is the root mean square of the deviations about the arithmetic mean of the data involved.

The simple procedure above for obtaining over-all tolerances is satisfactory for the majority of cases. When the distributions are such that the contribution of the components is not linear, due not only to the nature of the various characteristics but also to the mathematical relation that represents the resultant effect of the various contributory variables, the over-all variance is more difficult to determine accurately. For example, for three characteristics x, y and z, it is found that they may be combined as products, quotients, sums and/or differences. Thus the value xy/z consists of a product divided by the third variable. The theory of the propagation of error (4) covers this combination, but not directly. If full advantage is taken of the second and even third order effects that are evidenced by the form taken by the relation covering the over-all effect of all inspection items, a fairly good estimate of the variability may be obtained. In some instances, however, it is not necessary to know the over-all tolerance. Control is obtained much easier if it is exercised over the individual components. When the effect on the whole of each individual item is noted, then it is possible to determine how well the over-all product is controlled. Sometimes this is a little difficult at first, for it may be almost impossible to measure some of the items that contribute to the final result. Indirect methods of measuring or testing may be developed that supply the necessary information for obtaining the control desired.

It is not necessary in many cases to keep perpetual watch over all components. Some inherently remain in control. To achieve a tight control only the most important items need to be charted. When something starts going wrong in the process then it is the duty of Central Quality Control to account for the discrepancy as quickly as possible and have the proper authority instigate remedial action. This responsibility covers a wide range of possible troubles. A thorough knowledge of the process is required in order to properly evaluate the trouble and seek intelligently for an answer. When things start to go wrong, and before many pieces are produced, action should be taken to prevent a reoccurrence of the trouble. Preventative measures are always best. In many plants the fallacy of only looking at the end product is followed. This causes the Quality Control Inspectors to be mere screeners and destroys their initiative. Truly controlling the process by the judicious use of charts, tables and graphs, and taking action when required will make other groups anxious to apply Quality Control procedures. Careful inspection of a small sample from each lot will not only give an Acceptance-Rejection Plan that provides excellent protection, but it also affords an opportunity to apply control techniques to the inspection results and take action at the first indication of an unsatisfactory change in the process.

Electronic apparatus and equipment vary so much that it is necessary to use a variety of techniques in controlling their quality. Fundamentally, quality must be built into each unit. If the product is simple in nature

with very few requirements, it is possible to check only one or two key requirements and determine both the acceptance of the current lots and the ability of the product to meet its quality standards. One technique that has been used to a great extent in receiving inspection is the Lot Plot (5) system of inspection which is usually applied to the key characteristics. This system requires the recording of each measurement in a sample of 50 units, taking them in sets of five each. An estimate of the standard deviation based on the ranges is derived from $\bar{R}$ and the d_2 factor. Three sigma control limits then are determined from the relation $\bar{X} \pm 3\bar{R}/d_2$ and if these values are well within the tolerance limits and if the distribution of the 50 observations appears to be such that practically no units are outside the engineering requirements, the lot is accepted. If, however, the above conditions are not met, the lot may be rejected if it is very apparent that there will be a considerable portion of the product outside the specified limits. In questionable cases the distribution of the 50 observations is studied carefully and additional inspection by the method of attributes may be applied.

The procedure for the Lot Plot system is sometimes deemed to lack the sensitivity required for discrimination against unsatisfactory product and additional criteria are needed. A control chart for the averages of the ten sub-samples and also in some cases for the ten ranges is used and often proves a valuable adjunct for determining whether the lot shall be accepted or rejected.

In addition to the above techniques, sampling inspection plans based on variables may prove to be very helpful. In some instances where the standard deviations for a series of samples indicate control with respect to variability, the criteria may be based only on sample averages. These criteria also may be supplemented by attributes criteria applicable to the sampling results.

Another procedure that uses variables inspection data for a sample includes as the criteria the range as well as the average for each sample selected from a lot. It provides either lot-quality protection or average-quality protection, as prescribed, similar in nature to the sampling plans based on the method of attributes. Another procedure uses the standard deviation for the sample rather than the average range for a set of sub-samples and also incorporates many features of the attributes inspection plans now in operation.

The procedure using the range has not been developed to as great an extent as that employing standard deviation but it is simpler to apply. Early work on this type of criteria was given by Dr. E. P. Coleman in his Doctorate Dissertation. Work on the criteria using the standard deviation as well as the average is partially completed at the Stanford Research Institute (6) and is similar in nature to the sampling plans incorporated in MIL-STD-105A.

If use is made of all these criteria for acceptance and rejection of individual lots and in addition the data thus accumulated for these samples are plotted on appropriate control charts for the key characteristics for electronic components, the net results should be a quality product at minimum cost. The information that is obtained from such data may be profitably forwarded to engineering and provide a basis for determining whether the design changes are necessary on the final product. These

results, when supplemented by complaint and field reports should provide a fairly complete system of control for electronic components.

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SOME USES OF STATISTICS IN THE PLANNING OF EXPERIMENTS

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INTRODUCTION

In order to determine whether the aims of an experimental program are being met, every object of research or development is subjected to tests. The speed and certainty with which the aims are attained depend in large measure on the reliability of the test results and the correctness of decisions based upon them.

It is the principal function of statistics in experimental work to plan in advance and to guide the accumulation, analysis and interpretation of test results to improve their reliability and their usefulness to the authority responsible for decision and action.

To illustrate how this function is carried out, it will help to consider what may be called "a generalized plan for experimentation" (1), (2), (3) as shown in Table I.

TABLE I

A GENERALIZED PLAN FOR EXPERIMENTATION

A. Obtain a clear statement of the problem.
B. Collect available background information.
C. Design the test program.
D. Plan and carry out the experimental work.
E. Analyze the data.
F. Interpret the results.
G. Prepare a report.

This plan may seem as simple as ABC but it has sometimes happened that the first three steps have been neglected in some measure, and consequently the last steps have become a waste of time and effort. The kind of thinking involved in the statistical approach helps bring the importance of the early steps into proper perspective. The analytical techniques adapted to industrial uses during the past decade serve to improve the reliability of interpretations and to clarify the reporting of results.

A. STATING THE PROBLEM

Although the first stage of research is identifying and exploring new problem areas, a project does not firm up, usually, until a specific problem is outlined within limitations of current knowledge and techniques. A sound scientific approach to the experimental program requires that the exact scope of the problem be defined. This insistence on statement of the problem in advance has two purposes:

1. It focuses attention within a small area from which convincing evidence may be secured.

2. It meets the requirements of a valid conclusion that the problem be stated without reference to the result.

B. COLLECTING BACKGROUND INFORMATION

This step involves collecting of all existing information relating to the problem from the best available sources. Tabulation of pertinent data from earlier work when available has two advantages:

1. It avoids the necessity for repeating work already done, especially the repeating of mistakes.

2. It increases the certainty with which the new experiment may be planned and may reduce substantially the work required to disclose new facts.

C. DESIGNING THE TEST PROGRAM

As conceived under the statistical approach, the design of an investigation proceeds in three major parts: 1) holding of a planning conference of all parties who have an interest in the problem; 2) designing of the test in preliminary form; and 3) reviewing the program with all concerned. To illustrate this procedure, a very simple example involving textile chemicals is used. The problem is how to improve crease resistance of a textile material by varying the method of application of a given chemical.

1. The planning conference. At the preliminary conference, a meeting of minds is obtained on what propositions are to be proved. The proposition in this instance is that crease resistance can be improved by simply adjusting some of the conditions under which the chemical is applied to the fabric. Actually, statistical thinking proceeds from the "null hypothesis" that no improvement will be obtained and this hypothesis must be disproved if a revised treatment is to be acceptable.

Agreement is then reached on the amount of change which will be required to make the product more saleable or to justify increased cost of the improved treatment, or to be otherwise worthwhile.

Alternative outcomes of the program are considered, for example, an inferior result from the change, or an advantageous condition that would cost too much, or a treatment that would have a deleterious effect on the fabric itself.

A choice is made of the factors to be studied. By process of elimination, concentration of the chemical, temperature of application and drying temperature were chosen for the example. The range through which these factors are to be varied is decided upon. Perhaps even the specific levels of concentration and temperature will be determined at this time. In general, it is advisable to investigate the full usable range of the factors and to try enough levels to satisfy what is known about the likely behavior of the factor. For purposes of illustration, consider use of each of the three factors at its standard level and at some other practical level, designated C_1 and C_2 for concentration, T_1 and T_2 for application temperature, and D_1 and D_2 for dryer temperature.

The end measurements to be made are determined. In addition to measurement of angle of recovery in degrees, the problem requires measurement of tear strength which is important because it cannot be sacrificed for improved crease resistance.

Consideration is given to the possible importance of sampling variability, of the precision of test methods and of possible interrelationships (or interactions) among the factors. All three of these points are important in the example. Background information indicates that the position of the test piece in the swatch affects the test result and that measurement of the angle of recovery is a sizable element in the variability of results. It is likely that temperature of application will have a much more marked effect at higher concentration, resulting in what is known as "interaction" of the factors.

Consideration is given to the limitations of time, cost, materials, manpower, instrumentation and other facilities and of extraneous conditions, such as weather. There are many times when one or more of these considerations call for strict limitation of the number of runs to be made.

Finally, the preliminary conference takes into account the human relations angles of performing the tests. The necessity for gaining cooperation of all the individuals involved is clear.

2. <u>The preliminary design</u>. In the preliminary design of the test program, a systematic and inclusive schedule is prepared of the experimental runs to be made. This schedule may differ considerably from patterns used in the past because instead of varying one factor while all others are held constant, all factors are changed from run to run in a regular pattern. Provision is made for step-wise performance or for adaptation of the schedule depending on results.

Plans are made for the elimination of the effect of variables not being studied by controlling them, or by balancing out or randomizing their effects. The number of tests to be made is minimized within limitations of the information required. Available background information may assist materially in reducing the number of tests needed.

The method of statistical analysis which is to be used is chosen. Arrangements are made for orderly accumulation of the data.

The principal requirements of the design are to keep to a minimum the number of experimental runs, to get as precise a comparison as possible of the effect of changing levels of the factors, to uncover any interactions that exist, and, if it is not independently determined, to measure the experimental "error", or the variability introduced by the inability to reproduce exactly any particular result. Various methods of designing the program for improvement of crease resistance will be explained and a table will be used to compare how each meets the main requirements.

The time-honored method of changing one factor at a time is often referred to as the "classical design" and involves, for example, four runs with the combinations of the three factors at the levels indicated in Table II. It will be recalled that subscript 1 represents a standard level and subscript 2, a trial level of the factor.

TABLE II

CLASSICAL DESIGN FOR IMPROVING CREASE RESISTANCE

Run 1	C_1	T_1	D_1
Run 2	C_2	T_1	D_1
Run 3	C_1	T_2	D_1
Run 4	C_1	T_1	D_2

It is customary to make the first run at the standard level of each of the factors as a basis of comparison. In subsequent runs each of the factors in turn is varied to its trial level while the other two factors are kept at their standard levels. As a result, comparisons between C_1 and C_2, between T_1 and T_2 and between D_1 and D_2 are made on the basis of one result each. (Note that in much chemical testing or in ballistic tests, for example, the one result may represent an average of several tests on aliquot samples, or rounds, made during the same run.) Furthermore, unless independent information is available or each run is repeated, no information is given on experimental error. Lacking a measurement of error, it is impossible to determine whether an observed difference is large enough to be significant. Also, no information is given on the interactions of the factors because they have been varied one at a time.

The simplest form of statistical design, perhaps, is the "Latin Square". This is a technique for minimizing the number of runs and therefore has some shortcomings. A Latin Square arrangement for the sample program is given in Table III.

TABLE III

LATIN SQUARE DESIGN FOR IMPROVING CREASE RESISTANCE

	C_1	C_2
T_1	D_1	D_2
T_2	D_2	D_1

Run 1	C_1	T_1	D_1
Run 2	C_1	T_2	D_2
Run 3	C_2	T_1	D_2
Run 4	C_2	T_2	D_1

Involving the same number of runs as the classical design, it has one outstanding advantage in that comparisons between standard and trial levels of each of the factors may be made on the basis of averages of two results each. The averages of the two columns are used for comparing C_1 and C_2, of the two rows for T_1 and T_2, and of the two diagonals for D_1 and D_2.

Although larger Latin Squares will provide a measure of the experimental error, the design shown does not. No Latin Square uncovers interactions and in this respect Latin Squares are no better than classical designs. Small Latin Squares are particularly valuable if an independent measurement of the experimental error is available. They may be used

very effectively to screen out the most important factors among a large number under investigation. These important factors may then be grouped in a kind of statistical design that can separate effects of interactions.

The statistical design that maximizes the amount of information from a given number of runs is called a "factorial design". It involves simply making a series of runs with each level of every factor in all possible combinations. For large experiments, this may involve an unmanageable number of runs, so that a variety of useful techniques for reducing the number of runs without sacrificing essential information have been evolved. Handling of some of these designs involves considerable depth of understanding of the underlying statistics and no more can be done here than mention their tremendous effectiveness. For information on factorial design and on techniques for limiting the number of runs see References (4), (5), (6), and (7).

The full factorial design for the crease resistance example is given in Table IV.

TABLE IV

FACTORIAL DESIGN FOR IMPROVING CREASE RESISTANCE

	C_1		C_2	
	T_1	T_2	T_1	T_2
D_1	Run 1	2	3	4
D_2	5	6	7	8

Run 1	C_1	T_1	D_1
Run 2	C_1	T_2	D_1
Run 3	C_2	T_1	D_1
Run 4	C_2	T_2	D_1
Run 5	C_1	T_1	D_2
Run 6	C_1	T_2	D_2
Run 7	C_2	T_1	D_2
Run 8	C_2	T_2	D_2

It is possible under this plan to make comparisons between averages of four tests each, for example the average of all four runs under C_1 are compared to all four under C_2. The method of statistical analysis used, called "analysis of variance", results in ability to separate out effects of experimental error and of interactions among the factors.

It may be noted that the Latin Square is in effect one half of the Factorial Design. The effect of cutting the experiment in half, in this instance, was to lose all information on experimental error and on interactions and reduce the precision of comparison. For larger factorial designs, partial performance does not have so stringent an effect. It is also of interest to note that if the classical experiment is repeated, the same number of runs is required as in the factorial case. However, because of the inherent faults in the classical approach, accuracy of comparison is much reduced and interaction effects are still unobtainable.

* Table V provides a comparison of these designs in summary form.

TABLE V

COMPARISON OF CLASSICAL WITH STATISTICAL DESIGNS FOR IMPROVING CREASE RESISTANCE (3 factors, 2 levels each)

Type of Design	Runs Required	Tests Averaged for Comparison	Experimental Error Measured	Interaction Measured
Classical	4	1	No	No
Latin Square	4	2	No	No
Factorial	8	4	Yes	Yes
Classical (repeated)	8	2	Yes	No

3. Review of the design. All parties concerned are given an opportunity to make final comments on the program. The program is spelled out in unmistakable terms for the benefit of those carrying out the experimental work.

ADVANTAGES OF STATISTICAL DESIGNS

This kind of planning has a number of advantages which the older kinds of designs often did not have:

1. Close teamwork is required between the statisticians and the research or development scientists with consequent advantages in the analysis and interpretation stages of the program.

2. Emphasis is placed on anticipating alternatives and on systematic pre-planning, yet permitting step-wise performance and producing only data useful for analysis in later combinations.

3. Attention is focused on inter-relationships and on identifying and measuring sources of variability in results.

4. The required number of tests is determined reliably and often may be reduced.

5. Comparison of effects of changes is more precise because of grouping of results.

6. The correctness of conclusions is known with definite mathematical preciseness.

D. PLANNING AND CARRYING OUT THE TESTS

This phase of the work is not directly within the scope of the statistician. However, an orderly approach is desirable, as follows:

1. Developing methods, materials or equipment and applying the methods or techniques.

2. Applying theory and possibly modifying procedures in mid-course.

3. Attending to and checking details.

4. Taking precautions in collection of data and for recording progress of the program.

E. ANALYZING THE DATA

This phase calls for reducing the recorded data, if necessary, to numerical form capable of being analyzed. It requires exercise of care in applying the proper mathematical technique of analysis. Careful training must be given to individuals engaged in this work.

F. INTERPRETING THE RESULTS

When the individuals who undertake to interpret test results have a thorough background in the statistical method of thinking several advantages result:

1. Care is taken that consideration be given to all the data observed.

2. Conclusions are confined to strict deductions from the evidence at hand.

3. All questions suggested by the data are tested by independent experiments.

4. Conclusions are arrived at as to the technical meaning of the results as well as their statistical significance.

5. Implications of the findings for application and for further work are pointed out.

6. Accounting is made of any limitations imposed by the method used.

7. Results are stated in terms of verifiable probabilities.

G. PREPARING THE REPORT

A good report requires that the work be described clearly with a full explanation of the background and pertinence of the problem and the meaning of the results. Taking full advantage of the statistical method provides some extras:

1. Effective tabular and graphic means of reporting are used.

2. Sufficient information is supplied to permit the reader to verify the results and draw his own conclusions.

3. Data are presented in good form for future use.

4. Conclusions are limited to an objective summary of the evidence so that the work recommends itself for prompt consideration and decisive action.

CONCLUSIONS

The advantages of statistics in the planning of experiments are many. In addition to economy of time and effort, the reliability of results is improved and the decisions based upon them are of better quality. Some new techniques are introduced but in general emphasis is placed on exercise of good common sense. As a guide to readers who may wish to supplement common sense with the best that mathematical statistical science has to offer, a "Check List for the Planning Experiments" is appended to the paper.

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APPENDIX

CHECK LIST FOR PLANNING TEST PROGRAMS

A. Obtain a clear statement of the problem.

1. Identify the new and important problem area.
2. Outline the specific problem within current limitations.
3. Define exact scope of the test program.
4. Determine relationship of the particular problem to the whole research or development program.

B. Collect available background information.

1. Investigate all available sources of information
2. Tabulate data pertinent to planning new program.

C. Design the test program.

1. Hold a conference af all parties concerned.
   a. State the propositions to be proved.
   b. Agree on magnitude of differences considered worthwhile.
   c. Outline the possible alternative outcomes.
   d. Chose the factors to be studied.
   e. Determine the practical range of these factors and the specific levels at which tests will be made.
   f. Choose the end measurements which are to be made.
   g. Consider the effect of sampling variability and of precision of test methods.
   h. Consider possible inter-relationships (or "interactions") of the factors.
   i. Determine limitations of time, cost, materials, manpower, instrumentation and other facilities and of extraneous conditions, such as weather.
   j. Consider human relations angles of the program.

2. Design the program in preliminary form.
   a. Prepare a systematic and inclusive schedule.
   b. Provide for step-wise performance or adaptation of schedule if necessary.
   c. Eliminate effect of variables not under study by controlling, balancing, or randomizing them.
   d. Minimize the number of experimental runs.
   e. Choose the method of statistical analysis.
   f. Arrange for orderly accumulation of data.

3. Review the design with all concerned.
   a. Adjust the program in line with comments.
   b. Spell out the steps to be followed in unmistakable terms.

D. <u>Plan and carry out the experimental work</u>.

1. Develop methods, materials, and equipment.
2. Apply the methods or techniques.
3. Attend to and check details; modify methods if necessary.
4. Record any modifications of program design.
5. Take precautions in collection of data.
6. Record progress of the program.

E. <u>Analyze the data</u>.

1. Reduce recorded data, if necessary, to numerical form.
2. Apply proper mathematical statistical techniques.

F. <u>Interpret the results</u>.

1. Consider all the observed data.
2. Confine conclusions to strict deductions from the evidence at hand.
3. Test questions suggested by the data by independent experiments.
4. Arrive at conclusions as to the technical meaning of results as well as their statistical significance.
5. Point out implications of the findings for application and for further work.
6. Account for any limitations imposed by the methods used.
7. State results in terms of verifiable probabilities.

G. <u>Prepare a report</u>.

1. Describe work clearly giving background, pertinence of the problems and meaning of results.
2. Use tabular and graphic methods of presenting data in good form for future use.
3. Supply sufficient information to permit reader to verify results and draw his own conclusions.
4. Limit conclusions to objective summary of evidence so that the work recommends itself for prompt consideration and decisive action.

APPLICABILITY AND INAPPLICABILITY OF MIL-STD-105A

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American Iron and Steel Institute

I speak as a member of the American Society for Quality Control, and not as a representative of the American Iron and Steel Institute or the steel industry. My interest in Military Standard Sampling Procedures and Tables for Inspection by Attributes, MIL-STD-105A, 11 September 1950, is based on an association with governmental specification requirements which began in 1941 and on my belief that the following discussion will be helpful to the governmental services and to industry "for the purpose of establishing sampling plans and procedures for inspection by attributes" as stated on the inside cover of the Standard.

The American Iron and Steel Institute has not conducted any industry survey on the foregoing Standard; and, to my knowledge, the steel industry has not. However, I have discussed the Standard individually with technical personnel in the steel industry, particularly those men whose major activities concern the control of the quality of steel products and who have had experience in trying to apply the Standard to steel products.

Analysis of this Standard reveals that the sampling procedures and tables for the inspection by attributes which comprise the Standard have been developed from at least five fundamental considerations:

1. The articles to be inspected are manufactured by a process that is under statistical control; this means that the main sources of variability (raw materials, manufacturing equipment and operations and operating workmen) are controlled or controllable at satisfactory process average levels for the various inspected attributes of the articles;

2. Defects are randomly distributed within the articles and defective articles are randomly distributed throughout the lot; this means that defects and defective articles do not occur in identifiable sequences or "runs;"

3. The articles can be sampled on a random basis; this means that the articles in the sample are representative of the lot from which they are taken;

4. The sampling can be economically performed; this means that articles can be selected at random without significant disruption of the manufacturing process, without significant destruction of the articles or damage to the articles and without significant expense;

5. For a manufacturing process under control and samples that are representative of the lot, the quality of the lot can be evaluated from the quality of the samples within the risk limits that can be plotted in a conventional operating characteristic curve; those risk limits concern (a) the risk of rejecting satisfactory lots and (b) the risk of accepting unsatisfactory lots.

Misapplication of this Standard to flat rolled steel, such as sheets and strip, raises two questions which remain unanswered.

(1) How can a coil be sampled without producing two or more coils?

(2) How can sheets or strip in cut lengths be sampled in a random manner so that the selected cut lengths are representative of the pile from which they are selected?

When a purchaser requires the steel in coil form, the conventional method of sampling is to cut a specimen from each end of the coil. Those specimens represent the ends of the coil. The sample comprising those specimens is not necessarily a random sample; and the sample may or may not represent the remainder of the coil. But the purchaser wants the coil, not several coils that might result from the cutting of specimens throughout the original coil. The producer's experience in manufacturing coils for that purchaser, together with the purchaser's experience in using previously shipped coils, is the producer's guide in determining whether or not the coil should be shipped on the basis of the inspection results of the end specimens. The Standard takes no cognizance of the mutual experience of the purchaser and producer in evaluating the quality of the coil.

A more interesting problem arises in sampling a pile of sheets in cut lengths. Should every tenth or twentieth sheet be taken, so as to get a stratified sample, assuming the sheets are stacked or piled in the order in which they are cut from the coil? Or should a table of random numbers be used to determine the order of selection? In either case, is the sample representative of the pile? Again, the experience of the producer in manufacturing sheets for the purchaser and the purchaser's experience in using those sheets are the guide to the producer in determining the location and number of sheets to be sampled and in determining from the inspection results whether or not the lot of sheets should be shipped. The Standard does not recognize the mutual experience of the purchaser and producer in evaluating the quality of the lot of sheets.

In the case of cut lengths, the Standard offers only the following guidance on sampling, as quoted below.

"7. DRAWING OF SAMPLES.

"7.1 Sample. A sample is one or more units[*] of product drawn from a lot, the units of the sample being selected without regard to their quality.

"7.2 Frequency of sampling. The Government shall draw one or more samples from every lot, or, at its option, draw samples from the product intermittently.

"7.3 Time of sampling. The Government shall draw samples from the lot after all of the units comprising the lot have been presented for inspection, or, at its option, may draw samples during the course of assembly of the lot by the supplier."

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* "1.4 Unit of product. The term 'unit of product' is the entity of the product inspected in order to determine its classification as defective or nondefective. This may be a single article, a pair, a set, a length, an area, a volume, etc., of the finished product or a component thereof. The unit of product is established by the Government and may or may not be the same as the unit of purchase, supply, production or shipment."

The foregoing discussion of the inspection of coils and cut lengths is a specific example of the inapplicability of the Standard to MILITARY SPECIFICATION STEEL, CORROSION-RESISTANT (18-8), PLATE, SHEET AND STRIP, MIL-S-5059A, draft prepared by ASG as of Jan. 1951. That specification referenced JAN-STD-105. I have been informed that JAN-STD-105 has been superseded by MIL-STD-105A for the cited reference in MIL-S-5059A.

The foregoing brief examination of one case of misapplication of the Standard focuses attention on two of the five fundamental considerations previously mentioned, namely: (2) the randomness of the defects and defective articles and (3) the randomness of the sampling. It might be argued that the defects and defective articles must be randomly distributed for a process that is under statistical control. Essentially, this argument is that control of the variability of the process controls the variability of the product; and that, for a controlled process, any greater variability of the product is attributable to the so-called "operation of a chance system of causes;" consequently, when the chance system of causes is operating, the defects or defective articles likewise are produced in a chance manner and therefore they are randomly distributed. Is there any difference statistically between a process that is controlled at a level of 1 per cent defective as compared with the same process operating under different conditions that is controlled at a level of 20 per cent defective? Can we say that for each of those quality levels the defects and defectives are randomly distributed? Those questions are the introduction to the core of this discussion: for many materials that are produced in a continuously extended manner, such as a coil of strip or a bundle of wire, the defects within the coil or bundle are not randomly distributed; and defective coils and bundles are not randomly distributed throughout the production lot. Consequently, the Standard is not designed to evaluate the quality of such continuously produced materials. Furthermore, statistical theory has not developed a practical method of evaluating the quality of such continuously produced materials in which defects are not randomly distributed within a coil or bundle and defective coils and bundles are not randomly distributed throughout production lots.

The inspection of bars, as required by Military Specification STEEL BARS AND BILLETS, CORROSION RESISTING (FOR REFORGING ONLY), MIL-S-862A, 6 April 1951, is another case of the misapplication of the Standard. In MIL-S-862A random sampling is prescribed, as follows:

"4.3.1 Sampling for inspection.-- A random sample of bars or billets shall be selected from each inspection lot of material offered for Government inspection of visual and dimensional characteristics with lot acceptance based on the following sampling inspection requirements in accordance with Standard MIL-STD-105:"

An experienced producer of stainless steel bars and billets has found it necessary to inspect every billet and every bar because sampling inspection is unreliable. Furthermore, the entire length of each bar is inspected for surface characteristics, diameter and full cross section. Otherwise, bars having surface imperfections detrimental to the finish of the forging to be produced from the bars will not be detected. Billets that are conditioned to remove surface imperfections are rolled into bars

that sometimes do not have a full cross section. Bars that have any portion under the full cross section can result in forgings that are not filled out. Hence, each bar must be checked for full cross section.

The necessity for 100 per cent inspection arises from a distribution of causes of defects in the billets which may be random, but those causes result in a distribution of defects in the bars which is not necessarily random. The Standard does not apply in the foregoing case of inspection of visual and dimensional characteristics of bars because the Standard is based on the random distribution of defects in the product, among other things.

This discussion of MIL-S-5059A and MIL-S-862A in relation to MIL-STD-105A is confined to the second and third fundamental considerations on which the Standard is based because the inapplicability of the Standard to the inspection of products covered by those specifications appears to have been overlooked by the governmental services which have prepared the product specifications. Those products and others which are produced in a continuously extended manner require a new system of statistics for their quality evaluation, in view of the second and third fundamental considerations on which MIL-STD-105A is based.

MIL-STD-105A is not applicable to hot rolled alloy steel bars because some of the important defects can be nonrandomly distributed along and within the bars.

Other limitations of applying the Standard to such continuously produced materials are more apparent. They concern the fourth fundamental consideration, namely, the economy of sampling in relation to disrupting the manufacturing process, destruction of the articles or damage to the articles and the amount of sampling. It should be obvious that a continuous strip mill or a continuous annealing furnace must operate continuously; stopping the movement of the material for the purpose of sampling disrupts the process and can destroy or damage the product. Excessive sampling unnecessarily destroys product and increases sampling costs. Excessive handling damages product, particularly those products having a high degree of surface finish. Furthermore, the handling of 150 to 200 tons of material to obtain samples aggregating less than one ton can involve very high handling costs, and can seriously interrupt production when cranes and other production equipment are employed for sampling when they are required for production.

So far this discussion concerned the inapplicability of the Standard. However, there are many applications of the Standard to the inspection of articles currently being procurred by the governmental services. For those applications the five fundamental considerations, on which the Standard is based, are valid. From personal experience in World War II in applying similar standards to the inspection of many kinds of discrete fabricated articles, such as components of ammunition and tanks, for example, I recognize MIL-STD-105A as a standard that can have wide application.

In summary, I wish to emphasize the need for a reconsideration of the entire problem of inspecting materials produced in a continuously extended manner by procedures that are based on statistical methods, and most

particularly on those materials in which defects and defective articles are not randomly distributed, or for which methods of random sampling have not been developed, or both.

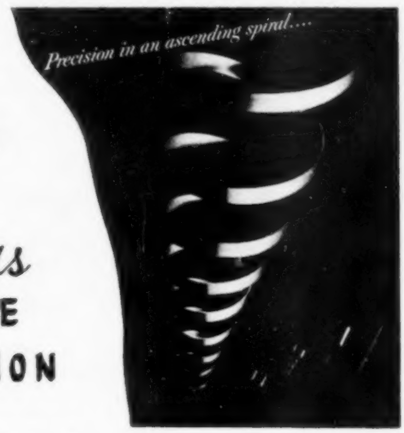
THE GAGE LABORATORY, ITS EQUIPMENT AND FUNCTION,
TO ACCOMPLISH PRECISION -- AN EVER-ASCENDING SPIRAL TOWARD PERFECTION

Clifford A. Wallace
Eastman Kodak Company, Camera Works

The current ascending spiral of finer quality through the current methods of Quality Control is greatly dependent for its success or failure upon a carefully implemented program of gage control. In any manufacturing process the product can be no better than the tools that produce it, and so it is with quality control, for some of its more important tools are the gages and measuring instruments that are used by the people inspecting the product.

THE GAGE LABORATORY

Precision
IS A FULL TIME JOB



Future Demands
WILL REQUIRE MORE AND MORE PRECISION

KODAK CAMERA WORKS

The question we want to discuss now is the importance of establishing a Gage Laboratory: to control the accuracy constants built into manufacturing gages and fixtures at great expense in order to produce products with interchangeability characteristics, which limits require gaging equipment to be accurate in tenths of thousandths or less, and to take advantage of the full manufacturing tolerances and natural wear of the gages for economic reasons.

Would your management consider that your accounting department was doing a good job if they used adding machines and calculating equipment that were off some three or four percent? Because we know such would not be tolerated, we have grown to respect the methods of the accounting division whereby each account is carefully balanced. The direct relation to profit and loss statements, the life-blood of any business, is readily seen here, but the same applies to gage control. I do not believe any of us could honestly defend conditions in our plants if there was no such thorough policy and organization maintained to control the extreme accuracy required in the gaging equipment.

In our plant at Camera Works we have about 4,500 people; almost 450 inspection and quality control personnel; over 200 different products, with 15,000 different parts and hundreds of thousands of different operations, from simple 3-dollar cameras to very expensive professional projection and photo-finishing equipment, and a number of government items requiring precision. These frequently involve combinations of mechanical and optical systems, and electronic circuits, and are required to work under almost all conditions found anywhere in the world at any time of year. Accuracies of plus or minus one- and two-thousandths are common; working limits of one-half thousandth range are frequently encountered; small fine pitch gears and range finder cams which compound effects of inaccuracies, are a few examples of the accuracies we control with gages.

If you had visited our factory just prior to 1941 you would have seen the culmination of a gradual change-over, from the system of having separate complete specialized factories within a large factory, to one of pooling all of the machine equipment and segregating them into single departments, such as press, milling and drilling, lathe, automatic screw machines, plating and finishing, which include expensive machines and tooling equipment capable of producing very high grade work, whereby all parts for all products now requiring such machining pass through the same department, after which they are assembled in separate specialized assembly areas completing the finished product.

Under these circumstances it can readily be seen that standardization in our gage control was indicated. Therefore, it was decided to embark on a more formal and comprehensive program than we had been using, and incidentally, more comprehensive than was in general use in industry. At this time, the tool and gage inspection department was set up and provided with —

Two Toolmaker's Microscopes
One Universal Measuring Machine & Microscope
One Supermicrometer
One Simple Microscope
One Optical Comparator
One Small Sine Plate
Several Dial Comparators
Several sets of Gage Blocks
Standard Measuring Rolls and usual small precision measuring tools.

Additional necessary equipment was acquired as rapidly as conditions and deliveries would permit. One of the initial additions was a Electrolimit Universal Internal Comparator, thus making possible accurate determinations of fixed gages for internal dimensions. Closely following this, a 48" Standard Measuring Machine was acquired, thus permitting mechanical measurements directly in one hundred-thousandths.

Several more Toolmaker's Microscopes and a relatively large number of Supermicrometers were added. Special benches were designed and built for convenient use of the super-mikes, since these instruments get a lot of use in a Gage Laboratory. Routine check of nearly all plug gages - plain, cylindrical, and threaded members - as well as thread setting plugs, are made on them. Other Toolmaker's Microscopes were added, such as the Gaertner. A Vinco Optical Master Dividing Head was obtained and with it the accessory Cam Rise Checker, thus providing a means of making accurate determinations of the various master Cams we use as well as some functional machine parts.

The growing realization of the need for more definite information on and control of surface finishes on gages indicated the need for improved surface finish analyzers which were then included in the equipment. This equipment, of course, provided surface roughness readings which is a function of the useful life of a gage.

Additional equipment, which we have since come to regard as indispensable, was rapidly acquired and included -

Bore gages covering a range of .7500" to 6.000" inclusive
Index Masters
Large Sine Plates for compound angles
Optical Flats
Cylindrical Standards
Additional Optical Comparators
Visual Gages of the Comparator type

and, of course, sets of Gage blocks in inspection accuracy as well as a master set of laboratory accuracy.

The key control was to make sure that the system would channel the gaging equipment in daily use in the many departments of the plant to the gage laboratory for determinations of accuracy. Wear in normal use was, of course, the greatest single factor in making such checks.

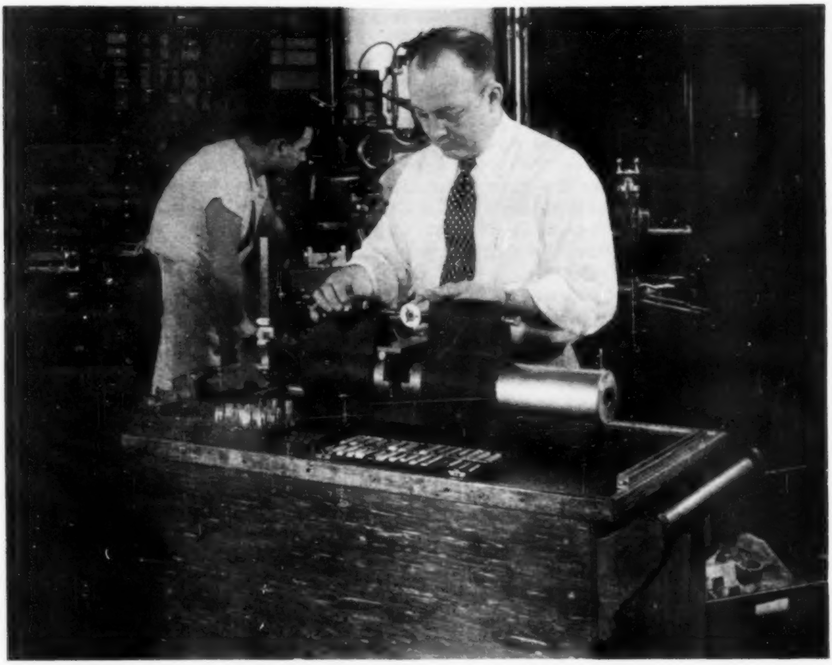
In the Camera Works, all gages are cataloged in a central Gage Control Office. It is here that the reserve stock so necessary for replacements is maintained. General gages, and this category includes all such items as plain and threaded cylindrical plug gages, both double end and extra members, plain and threaded cylindrical ring gages, various types of indicators, micrometers, verniers, thread and gear wires, and so on, are all stocked in carefully labeled drawers for easy and immediate access. Incidentally, all general gages in Camera Works are cataloged and stored by size - not by part numbers.

It is to this control point that equipment checked and accepted by the gage laboratory is delivered for cataloging, stocking of extra members, and distribution to the ultimate use locations. These are the Tool Cribs, or Tool Vaults as we call them, in each of the many machining and assembly departments. Here again, the gages are stored in drawers by size and are issued to the operators with the tools for the job. The tools and gages required for each operation are shown on a department operational sketch.

At this point the "perfect" gage issued to the operator can no longer be assumed to be correct and, of course, the longer he has it and the more he uses it, the less we can feel that it retains its original characteristics. Inasmuch as the great majority of machined jobs at Camera Works are of a short run nature, we have been able to feel secure in allowing gages to remain with a job for the duration of the job or until the end of the shift, depending on which is shorter. At this time when the gages are returned to the tool vault, they are placed in padded trays, rather than back in their storage compartments, and are sent to the gage laboratory for measurement.

MEASUREMENTS STANDARDS ROOM
Temperature Controlled
68°F ± 2°

In the relatively few cases where jobs run for extended periods, gages are permitted to remain at the machine and are checked there by a traveling gage inspector whose mobile inspection truck is equipped with a Supermicrometer, Gage Blocks, Cylindrical Standards and Thread Measuring Wires.



PORTABLE GAGE CHECKING EQUIPMENT

Built-up or fixture type gages are handled in very much the same manner except that frequency of checking is determined by inspection and production supervision based on intimate knowledge of the part and operation. The checking is, of course, done by the gage laboratory.

At the present time we have at Camera Works in excess of 100,000 gages, with more than 500 thread set plugs. More than half of our general gages are in sizes below 1/4-inch, and the great majority of our threads, exclusive of the machine screw sizes, are of the fine pitch variety.

In the overall picture of our procedure, the gage laboratory is the vital mechanical heart. While we feel, quite obviously, that precise mechanical control of our gages is essential, we also feel very strongly that these same gages shall also be of the type and in the quantities that will be required, and that we shall have them for all the dimensions that require them. To accomplish this we have created a procedure whereby, when new models are released by the Design Engineers and assigned to Process or Product Engineers for Tooling, the Gage Engineer and the Quality Control Engineer meet at this point with the Process Engineer, review the tool layouts with him, and specify the gages which they feel are essential for each operation. These gages are immediately written in on this original layout and thus become an integral part of it. From this point on, tools and gages are ordered together. Requisitions are written for those which can be purchased as catalog items (this includes all the general gages), while designs are made for those of the built-up type, such as location, flush pin, optical, electrical, etcetera. The written orders which are transcribed from the tool layouts are routed through the Gage Engineer for his approval. This serves the dual purpose of providing a routine double check on the accuracy of the re-written data and stipulation of required quantities in addition to making it possible to observe trends in gage life as reflected by replacement orders, and to keep informed on additional gages which may have been requested by individual departments on current models as indicated by specific problems which arise occasionally. In brief, no gage can be ordered without the knowledge and approval of the Gage Engineer. Eventually, the designs of special gages are sent to the Gage Engineer for approval. It should be understood that this is an approval of type and suitability rather than as a substitute for the usual designer's check for accuracy of computations. All this is as it should be since the gage is as much the tool of the inspector as the lathe is of the machinist.

This supervision of the Gage Engineer over original specifications for and subsequent additions to the gaging equipment has many desirable aspects. Specific policies can be more readily followed, and policed when necessary, because of the required routing of orders and designs.

This is the method that made it possible to enforce the use of universal equipment whenever practical and thus expedite the trend away from the excessive use of fixed, single purpose gages. The advantages of such a policy are many. Lower first cost and the tangible reflected economy in tooling costs for a new model are desirable. No less important is the immediate availability of equipment that may be purchased. The savings effected by having equipment available, thus eliminating the time lost in designing, building, and checking special purpose gages is somewhat intangible but, nevertheless, parts made without proper gaging on hand when required are not always acceptable. The rejections and consequent loss from this reason are not usually recognized as the result of "gages on order". The value of relieving the tool room load should by no means be overlooked.

It is inevitable that, with a gage laboratory such as ours, there will naturally be rejected gages. The laboratory people adhere rigidly to the specifications for the gage at hand whether it is a new plug gage or a repaired fixture gage. It is essential therefore that the reports of their findings on rejected new equipment be examined and evaluated and a decision on the disposition of the material be rendered. This also is one of the functions of the Gage Engineer. He reviews the data, and, considering the factors such as seriousness of the defects, how pressing the need for gage may be, etc., indicates what disposition should be made in each instance. On purchased equipment this may be to repair either at the supplier's or our own expense, or to return the material to the supplier for correction or replacement. Much of this is done in close cooperation with the purchasing department.

As is true of so many manufacturing industries today, it is more economical to procure certain components from others who specialize. This sub-contract program is frequently serviced with duplicate gages from our own program or, if the parts are made exclusively by vendors, they are customarily considered in the gage layout and gages are furnished to them which may be returned to our plant for periodic check. The Quality Control Engineers who visit these outside facilities frequently observe the condition and use of gages and recommend checking or replacement if conditions indicate this to be necessary. The responsibility for delivery of gages for sub-contractors rests with the Gage Control Stock group who proceed with this function on the basis of information automatically supplied to them on the tool layouts.

No discussion of gage control can be complete without some mention at least of the importance of surface finish and its relation to gage performance. You will recall that surface finish analyzers were added to the laboratory equipment. Their use over the years has been so beneficial that rejections of gages for unsatisfactory surface finish are now rare occurrences. Gages with rough surfaces, of course, have relatively short lives since a small amount of wear removes the high points over which original measurements were made. The early work in making our wishes known to our gage makers,as regards surface finishes, has been extremely beneficial in this respect.

It seems appropriate to include some reference here to certain special pieces of equipment, normally used in the plant proper, because of their effect on the gage control program. These include the gear checking instruments which we call Kodak Conju-gage Gear Checkers, made at Hawk-Eye Works. With them we are able to measure, and make proper tape records of these measurements, of all the precision gears which form a large part of our production. The point to observe here,however, is that we do not use a circular master gear which is both difficult and expensive to make, but even more difficult and expensive to check, but rather a more economical flat master worm section which can be both made and checked more precisely than any circular master gear.

A similar example is the Kodak Contour Projector which is also built at Hawk-Eye Works. With appropriate glass charts and staging fixtures we are able to check accurately both hole diameters and locations of the many holes in fuze plates to tolerances in many instances to the order of .0006" magnitude. This equipment has eliminated the need for literally dozens of the old fashioned type of sliding pin gages. Here we have something far better and very definitely less expensive. The

accuracy of sliding pins is always debatable and by eliminating them in favor of an optical method, we get more precise results plus a simultaneous hole diameter inspection, thus eliminating hundreds of plug gages. The advantages here are certainly obvious.

The system we employ fits our needs and our organization. The system recognizes the design specification limits to be the standard supreme. From the design specification on the drawing to the creation of a part exactly according to the design specifications, an amazing number of things and people are involved.

It is the growth aspects of an organization in an activity like this, and the overall perspective that is interesting. Actually, all of the measuring and checking of gages and the operation of our temperature controlled Gage Measurement Laboratory are now operated by our tool and part checking group in our Toolmaking Department. This function started out some ten or more years ago as a separate gage control function. But, after first thoroughly centralizing the principal whereabouts of all gages used in the plant, standardizing on all inventory, appointing a gage engineer to maintain the standardization and efficiency of future gage stock supplies, and establishing gage vaults throughout the plant in appropriate manufacturing centers, we have gradually integrated with our Tool Manufacturing and Repair activities the gage control function trained specialists and facilities to the point where there is now no duplication of effort or space. About the only autonomy, if you will, is the Quality Engineer (gage specialist).

Planned or not, the making of parts to dimensions outside specified limits can be traced indirectly to lack of authority and to lack of equipment to maintain accuracy of gages in a plant.

Gage control then, as we know and practice it, is the system we have outlined, for we find it gives us two things we want very much - better products and lower overall cost.

The optical method of measurement has become so useful that our Hawk-Eye Works, Optical Division, found it necessary to make some working instruments of their own. For your information we have brought along the colored movie which demonstrates and explains the optical method; it also covers the checking of gears by the principle of using flat master sections to check circular gears. These two pieces of equipment would simplify the methods and improve the precision of measurements in the fields where they apply.

Gage Control Sub-Group.

Before summing up, I think you would be interested in the work of the Gage Control Sub-Group of the Rochester Society for Quality Control which was formed in 1945 after the first Annual Clinic of the Rochester Society. The writer was asked, after leading a meeting on "Quality Control through Gage Control", if those in attendance could meet again. The philosophy of the "quality" of Quality Control being very dependent upon careful control of the gages touched the key of so active a problem that many wanted to do more about it. Some of the questions related to gaging policies, standards used, gages for sub-contractors, methods of repairing steel gages, to mention a few.

Since February, 1945, this sub-group has met regularly without interruption. The membership is made up of one to four members from each of our principal industries, among them chief and assistant engineers, quality control department heads, plant superintendents, general foremen, tool department heads, foremen-tool room, chief and assistant inspectors, chemical laboratory head, and others from all parts of a company's organization.

The general feeling was that there were many phases of this new subject which could well be developed through the medium of group discussions and by calling upon specialists in the various phases of gage work to speak to the group and submit to questions following the talk. These various talks have covered many facets of the gage picture such as the following representative topics:

"Inspection by Optical Projection Methods"
E.C.Polidor - Univ. Engraving & Color Print, Inc.
"The Practical Side of Gage Design"
H.Rekers - Rekers & Roessel
"The Unseen Factors in Gages"
C. H. Bauer - Cadillac Gage Company

as well as others covering screw threads, unified threads, metallurgy, etc.

Officers consisting of a Chairman and Vice-Chairman were elected and regularly scheduled bi-monthly meetings were held three times a season. Elections are held annually. The vice-chairman is, by custom, elected chairman, and a new vice-chairman is elected, the candidate having been proposed by a committee appointed by the incumbent Chairman.

Continuing interest in the group is shown by the regular meetings at which the average attendance is about forty men. This roughly indicates that the meetings have been and still are of value.

The formation of a similar group here might well be considered as a beneficial tool for the gage people of this area and they, too, may find as we have in Rochester that the benefits far outweigh the minor inconveniences of operating such a group.

No doubt there will be more questions which I shall be glad to answer later. I feel that you will want to know something about the economic factors of such a program. To equip a Gage Laboratory with the items with which we started out, the cost in today's market would be about $60,000.00, $18,000.00 of which would be for a Societe Genevoise d'Instruments de Physique Universal Measuring Instrument. A suitable air-conditioned and temperature-controlled room would cost between $30,000. and $40,000., depending on locality. There would be a personnel ratio requirement of one gage control person for every 150 production employes, but that would be even less if you already had a good tool-checking set-up. The cost-wise control of the expenditure for the gages is a proper responsibility function of the Production Engineer, who is accountable for the tooling and production layout to accomplish the successful manufacture of an item, but the policing of the system for the maintenance of accuracy in the gaging equipment can very properly be the responsibility of a Quality Engineer gage specialist.

We have found that interchangeability of parts, even on simple, low-priced products will lower assembly costs, repairs, and servicing and that overall better parts means less scrap.

It should not be too difficult to survey the possibilities of a Gage Laboratory paying for itself in a surprisingly short time. We found that so when we added up the savings accrued when we got together some $800,000. worth of gages and began our standardization program.

A first-rate gage control system, therefore, is necessary

1) In order to achieve a state of interchangeability of parts.
2) Because complete quality control cannot be achieved without adequate gage control provisions.

A COMPLETE STORY OF THE OPERATION OF A RECEIVING INSPECTION DEPARTMENT

Archie R. Jackson
Allen B. Wrisley Company

No single phase of Quality Control has as wide spread applications or affects as many departments and operations as the Receiving Inspection Function. At the upper end of the industry scale, the material being received is covered by detailed blueprints, specifications and association agreements which are vigorously enforced by all parties. At the lower end of the scale, they deal in strictly commercial materials where price and delivery are the main considerations and it is just understood that you take what you get. Somewhere between these two extremes lies the type of material most everybody uses. In spite of the necessity for a Receiving Inspection operation, many industries have not gotten into the act. This may be due to incertainty of how to start. What plan to use. How to administer it. Maybe we can get along without it. Most Quality Control and Inspection people have been introduced to various types of Sampling Tables, their Operating Characteristic Curves, and even Classification of Defects. However, the main difficulty to me appears to be in just getting started; so we are going to spend this session narrating our experience by discussing "A Complete Story of the Operation of a Receiving Inspection Department".

Nature of the Business

To gain some idea of the importance of this Receiving Inspection Function, we should consider the nature of business to which it is related. Ours is Soaps and Cosmetics with a very wide variety of products. We average about 2,500 active products which are in a constant state of change. It is the very nature of the business that product, packaging, or merchandising seldom is the same from year to year or even from season to season. Some of the items carry the Wrisley label but itemwise we make more under customer labels, which we call Private Brand. They are made for the leading Department Stores, Grocery Chains, Drug Chains, Jobbers, Perfume Houses, Industrial Users, Laundries, Wagon and Truck Routes, and etc. Each one has different problems which are reflected in their products' specifications and hence in the Receiving Inspection Operation. In general, the products consist of: Milled Toilet Soap, Liquid and Soft Soaps, Soap Flakes both pure and filled, Milled Soap Flakes, Tower Blown Soap Granules, Ground Soap Granules, Hand Cleaners, Wall Cleaners, Bath Salts, Bubble Bath, Creams, Lotions, Colognes, Hair Dressings, Shampoos, Gift Sets, and Glycerine. From this variety of products and customers, some idea of the magnitude of the problem it presented to control the quality of the incoming components may be seen.

General Conditions Prior to Setting Up Receiving Inspection

Prior to the setting up of a Quality Control Department with a Receiving Inspection Operation, our situation was much the same as any organization which has attempted to get along without a Receiving Inspection Department formally checking each lot as it is received and recording its findings. As material was received, it was checked in for quantity; samples given to sales, purchasing, and development for their comments and decisions; and placed in the warehouse. As it was requisitioned out for use we also depended on the factory user of the productive material or packaging supplies to check their quality and performance. This might be within a few days after it was received or a matter of months. When

things were found wrong, operations came to a jarring halt; but not always before there had been a lot of lost time and scrap. Under such conditions it was inevitable that many things went through unnoticed or not reported, to be picked up later by the customer or sales personnel. Reporting of such difficulties back to the sources of supply, weeks or months after the receipt of the material, did not always promote the best of Vendor-User relationships. Difficulties experienced in the use of the material and the resultant lost time in the plant were worrisome. The time lost in failure to meet schedules and being forced to sort the acceptable product from the unacceptable were heavy cost items. On top of all this, we had no way of evaluating or checking the level of the quality of the materials coming into the plant.

Planning the Physical Set-Up

The setting up of a Receiving Inspection was not new to me; I knew that much preparation work must be done before it could become a going operation. Wrok must be started on different phases to meet a coordinated time schedule and not hold up its progress. The actual Receiving function was concentrated in two spots: One to handle truck and tank car shipments of basic fats and chemicals; the other to receive the balance of the wide variety of materials. The physical arrangement of our plant lent itself well to this operation as there were definite control points through which the material had to go before it could have the Receiving Manifests made up for admittance to Stock Rooms and Warehouses. Adjacent to this Receiving Area, we located our Receiving Inspection Office and Testing Area. Space was set aside in which to hold temporarily the shipments awaiting sampling and clearance of the material. While this was being prepared, we started work on our Inspection Plan and Procedures.

How Detailed Information Do You Need?

Only a very small per cent of the items to be inspected had any specifications beyond price, delivery, and of a general agreement to be commercially acceptable. The task ahead appeared to be long and detailed. The 2,500 different basic Commodity Numbers were multiplied by as many as 20 point numbers covering each of the productive supplies and packaging materials. This ruled out an initial full and completely detailed Inspection Procedure for every Commodity Number and Point Number. The classification of Inspection Characteristics into varying degrees of seriousness such as: Critical, Major, Minor, and Incidental would multiply the problems again. The use of different Quality Levels for certain items and/or characteristics would require several Inspection Plans which would in turn complicate the Inspection work. No previous knowledge of Vendor's History or Process Averages was available. Each item as received may be a one time proposition or continue for years. The selected plan must encompass all these problems and be fair to both the Suppliers and the Company.

Information Contributed by Other Departments — General Characteristics Become Specific

We gathered together all the information we had available from Purchasing, Sales, Product Development, Laboratories, and Factory. This was grouped as related to general classes of materials or products without trying to tie it down to specific items. This served as the framework for the general Inspection Characteristics. We followed this form for specific Commodity and Point Numbers and now changed just weight in general to so many pounds or ounces. Color became red per sample, proof, or color book. Size would now be a definite dimension, say 6-3/4 inches $\neq$ or -1/64 inches. Grain of paper to run length of cut sheet. Caps to fit a

specific bottle, gauge, and etc.

Information in the Individual Part Folders

This information was all recorded on a Receiving Inspection Procedure Sheet. Testing methods to be used, manner of storage, experience of plant with item, trouble due to it as reflected in customers' complaints, and in general our combined experience with the item is all shown. This is added to as time and conditions warrant. Each Commodity Number and Point Number has an individual folder in which all our records relative to it are placed. This includes this Inspection Procedure Sheet, Purchase Orders, Correspondence, copies of all completed Receiving Inspection Reports, supplementary tests of Laboratories, Rework Orders, and Quality Control Floor Check Reports.

Selection of Sampling Plan

While the work in preparing these files was going on, we also decided on the Inspection Plan we would use. The plan chosen was a True Sequential based on an Acceptable Quality Level of 2.0%, an Unacceptable Quality Level of 10.0%, a 5% Risk of Rejecting the Acceptable Quality, and a 1% Risk of Accepting the Unacceptable Quality. No previous knowledge of suppliers or Process Averages is necessary with this plan. Changes in the selected Acceptable, Unacceptable, and their related Risks has a corresponding effect on Sample Size and Acceptance and Rejection Numbers. To attempt to discriminate between say 1% and 3% quality will mean a larger sample size and hence more inspection. Taking less risk will have the same effect on sample size. The reverse holds true also for conditions going the other way. No classification of defects as to varying degrees of seriousness was done, as any lot which does not meet the Acceptance Requirements is reviewed and dispositioned within 24 hours of the time it is received.

We Take a Look at Present Incoming Material

Using this selected plan, we started collecting some data. This we did by inspecting every shipment received for three consecutive months. The normal procedure of just accepting all lots as received was still carried on. We kept our records to ourselves until the test period was finished. During this time each month stayed between 25% and 32% defective for the characteristics listed.

Introduction of Plan to Management

We then made our results known and advised our company that starting next month, October of 1947, we would inspect all incoming Productive Material and Supplies. This we did by means of a write-up covering the Sequential Plan, its values, mathematical justification, and use of either the Graph or Table by means of the one page of inspection instruction. (Armed with this write-up a Plan may be developed for any given Acceptable and Unacceptable Qualities.) Our Purchasing Department so advised our suppliers. We now had a fairly good picture of just what kind of material we had been receiving in the past and a yardstick against which we could measure future results.

Types of Reports Compiled from Receiving Inspection Information

Starting with October 1947, the results of our Receiving Inspection were

made up in monthly reports in which we showed the information in two ways:

1. By Commodities in which we compared Suppliers furnishing the identical or same type of commodity. On the face of the report, we showed a chart portraying the monthly Percent Defective and what happened to the material. Each month we extended these figures to show present and past history. Also shown was the number of suppliers furnishing commodities falling into different brackets of defectiveness. The body of the report shows general heading of types of items and within that group the Supplier, Description and Commodity Number of the items; Number of Pieces Received; Number of Lots Received; the Percentage of Pieces Defective; Reworked or Sorted; Salvage or Repair; Accepted with Deviation; and Rejected. At the extreme left, we showed the amount and type of defects by a code for each item as ready reference.

2. By Suppliers with all the commodities they had furnished. The cover showed a summary for the month of the various percents in each of the percentage categories listed above. It also showed a monthly percentage figure for each of the various types of coded defects. On the next page we showed an Honor Roll listing alphabetically all the suppliers who had perfect records for the month; also the number of pieces they had supplied and the number of lots. Later we included in parentheses, the number of times that year they had been on the Honor Roll. They became our Preferred Suppliers. The body of the report showed only the suppliers who didn't make the Honor Roll and gave their monthly record for all items they had furnished. It also included the same detail as in the body of the Commodity report but accumulated it by Supplier.

Customer Furnished Items were handled on a separate report in the same manner as above.

Items which were not sampled using the Acceptance Plan but using the industry practices instead for sampling were shown on a report for Chemicals and Colors by point of use.

Basic Fats and Oils were the last added. Here again, the sampling methods and testing procedures are tied in with industry practice. Results are charted on a transparency from which prints are made at regular intervals. New results are posted on the master and the prints then show both the past and current information. Detail records by suppliers furnish valuable records in the Raw Materials Department.

Actual Procedure in Inspecting a Shipment

1. When material comes to the Receiving Dock, a Receiving Report is made up which indicates the Shipper, amount received, and storage point. It is placed in the Inspection Area and cannot move until released by Receiving Inspection.

2. A random sample is selected and checked for all the characteristics on the Receiving Inspection Procedure Sheet.

3. If it is accepted by the Plan, the Receiving Report is stamped Accepted, signed and dated. The Receiving Inspection Report made out for each shipment shows the acceptance with no defective characteristics, and it is placed in the Parts File.

4. This Receiving Report admits the goods to storage and releases it on

the Production Control and Warehouse Records as available for use. No goods are placed in storage without this release and the permanent book tissue copies of the Receiving Reports are checked each morning to be sure everything has been inspected.

5. Each shipment as received is shown on a numbered Daily Record for quick reference as to what happened to the lot and where it was stored.

6. If the shipment was rejected by the Plan, the results of that inspection are shown by Characteristics and by Piece on the Receiving Inspection Report. The paper work with proper and representative samples of the defective material are taken directly to the Purchasing Agent. After looking it over, he may sign the Report to Accept the Deviation or Reject the material. Rather than return the shipment, he may contact the supplier and explain the difficulty or ask him to send somebody in to look the material over. The decision may be to Sort Out the bad material or Repair or Salvage it in some manner. On work of this kind, we usually secure a Job Number against which we charge the labor with the suppliers prior consent. Whatever the decision, it is signed for on the Receiving Inspection Report. If Purchasing does not want to take the responsibility alone, we will secure the affected Sales Department's approval for the action also. If it involves extra hardships on the Factory, they sign for it. An additional manner to handle shipments has been added in the past year. It is "Accepted Pending Inspection in the Plant" to cover items which can be handled most economically in this manner. In every case, the report constitutes the written approval of the conditions we have called to their attention. Since Quality Control is not fully relieved of their responsibility by these signatures, action taken which does not appear proper can secure full approval by getting Top Management to sign for the material. Shipments are not usually returned to the supplier unless that is the best way to handle it and the action will not stop or hold up the production schedules.

Reaction of Suppliers

After several years of experience in Receiving Inspection, we have found that our suppliers are also happy over the arrangement. Whether or not they have a Quality Control Organization, they report that knowing we inspect their material keeps them on their toes and provides them with a measure as to the kind of job they are doing. If we accept their shipments they know they are turning out a good product. Rejections are discussed with them before they actually happen. Sorting jobs are discussed fully before they take place and save them money in shipping charges.

Quality Improvement

It has been our observation that the quality improved greatly as soon as our supplier knew we were inspecting their shipments. In fact it dropped from 27.5% the first month to less than 10% in three months and has improved steadily since then. Once they knew what we wanted, they made the improvements themselves and it was not necessary to change suppliers except in cases of incurables.

What Form of Distribution Does the Material Coming to You Have?

An interesting thing we have noted is that even on our test checks in

Receiving Inspection, the material submitted to us never did have a distribution approaching a normal curve, with the bulk of shipments near the mean and diminishing out on either side. After just a few months and up to the present time, shipments are either very good or very bad. This is shown in the monthly figures when over 95% of shipments are 2.0% or better and are accepted. 3% are 10% or worse and are rejected. Only 2% of shipments fall between the 2% and 10% levels. For that reason, we feel that a plan which accepts or rejects on a small first sample saves on inspection expense, and our Sequential Plan does just that.

Comparison of Sequential to a Standard 2% Lot Tolerance Plan

Take our average lot size and submit it to our Plan and then to a standard 2% Lot Tolerance Double Sample Plan, which would be even more economical than the 2% Single. Considering the selection of the samples and the time to inspect the parts by both plans as your main items of expense, we found that in 98% of the time we accepted or rejected on our minimum first sample of 54. If we had been using the 2% Lot Tolerance (with the .81 - 1.00 process average) and just considering the first sample only, it would have increased our load twelve fold to 640. We do no sorting or detailing of rejected lots but would have to do so with the other plan. While we do receive some repeat shipments, most of them are one timers. Under such circumstances, it would be difficult to develop Process Averages to get the full advantage out of the 2% Lot Plan. There would be some difference in the Operating Characteristic Curves of the two plans. We have had excellent success with our Sequential Plan.

Efficiency of Receiving Inspection Checked by Plant Experience

Since we have Quality Control all through the operations, we have opportunities to see just how efficient our Receiving Inspection really operates. During all of 1951, we only found three cases where our plan admitted material which it should have caught. But even this was less than our calculated risk as it was set up to accept 1% of shipments due to chance alone that were really 10% defective. Now when material has been accepted, we feel safe in scheduling production involving its use.

Personnel Required

Now just what does it cost to handle such a set up? One full time man handles it all, even to following through and securing most of the approvals for the Receiving Inspection Reports where necessary. The making up of the Monthly Reports is an Office Function. Likewise the securing, posting and issuing of the Fats and Oils Report.

This is the Blueprint. You can Follow it Easily.

All in all, it is a fairly compact set-up, designed and built for our type of Operation: Details where they are required; knowledge of materials and their intended uses; with simplification when it will do no harm.

QUALITY CONTROL IN PRECISION MANUFACTURE

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While it is customary in industry, wherever a precision product is manufactured, to have an inspection department or a quality control department, or both, and while it is also customary to charge such departments with the responsibility for controlling the quality of product throughout the plant, it cannot be taken for granted that quality of product can or will be controlled.

It is fundamental that the quality of product must be the concern of top management and of every department in the organization. Quality can not be inspected into a product nor can Quality Control techniques in any way improve or increase the quality of product, but can only show what action will improve quality.

Quality must start with Engineering and Sales. The product must be designed to accomplish the purpose intended and to satisfy the customer; the product must be so represented to the customer that only what the design specifications provide for is expected. In addition, the design must be such that it can be manufactured and at a price the customer is willing to pay.

Next in the chain of "Musts" for quality is a production engineering program such that tools, equipment and methods are provided to produce quality product consistently. Such a program should also provide adequate and ample gages and gaging equipment to detect off spec product at the machine.

Another must for quality is a manufacturing organization whose supervision is quality-minded and makes every effort to produce a quality product and to instill pride of workmanship in the working force.

Superimposed on the preceeding conditions are factors which can and do affect quality and which need therefore to be purged of characteristics detrimental to quality. In this category are such factors as scheduling, material handling and storage, housekeeping, flow of material in the shop, production planning, tool and equipment maintenance, material procurement, union contract, industrial relations policies, time study, accounting, packaging and shipping.

The control of quality in precision manufacture ranges all the way from a minor problem in the case where a single person manufactures a single product to a very complex problem requiring the full-time of hundreds of persons in the case of large industrial plants.

In the latter case clearcut regulations must exist as to the authority of the Quality Control group and the amount of money that must be spent on quality control will reflect a true picture of the top management policies, the quality of design and production engineering and the caliber of manufacturing supervision.

The normal industrial community falls far short of the ideal due to many factors, chief among which is the human element. It is impossible for the individual in a large industrial community to know or anticipate the results of his every decision and action on the community. Therefore,

designs are not perfect, methods and tooling still allow scrap and rework, scheduling does not always allow time to manufacture, parts do get damaged in handling and stores, specifications are misunderstood, etc.

It then becomes a case of inspection and quality control to the rescue. The customer must be kept from receiving unsatisfactory product and the cost of the cumulative mistakes of the entire organization must be controlled to an extent that still permits operation at a profit.

This rescue effort is never ending. It is always a continued effort to mold the industrial community into the ideal form and a policing action to insure that it stays there.

Let's look at what it takes in the line of a Quality Control department to accomplish such a task. The prescription depends entirely on how sick the patient is and the cause of the sickness. Typical causes are growing pains, unbalanced effort in major divisions of the organization, overambitious department heads, lack of top management understanding, lack of sound policies or underestimation of the need to plan for quality.

The normal industrial community which has reached a reasonable size requires a quality control program that provides for inspection of incoming material, inspection of material at machine and process points, inspection and test of final product and provision for trouble-shooting. Adequate facilities should be provided for inspection and testing, and the knowledge and use of sampling plans and statistical techniques for "In Process" control and trouble-shooting are a must. The authority to control quality must exist and a liaison must be maintained with all other divisions of the community to collectively take the action necessary to protect both management and the customer.

Should the industrial community suffer from any one or a combination of the diseases previously mentioned, then the quality control organization must in addition provide accordingly. For example, lack of top management understanding of the quality problem requires a selling program, based on facts, by those charged with the quality control responsibility in order that the fundamentals of producing a quality product are realized. The effect of unsound policies on quality must be demonstrated. Overambition of top departmental supervision which may evidence itself in designs that can't be produced or too much emphasis on quantity production of poor quality product must be exposed by facts based on the economic affects on the community. Underestimation of the need to plan for quality also must be brought out into the open by facts which show the dollars and cents results of such neglect.

To sum it up, the control of quality in precision manufacturing requires a top management supported Quality Control department that has the cooperation of all other departments and that understands and assists the other departments in accomplishing their jobs in such a way that a quality product can be profitably marketed.

While in the overall picture all successful quality control programs have much in common, the degree to which the program can be made effective in preventing the production of defective product is decided by many factors. These are factors not under the direct control of the Quality Control department; factors that because of their interaction with every phase of the business do not lend themselves to any fast corrective action. Many examples of such factors can be found in every business. One that is fairly common in industry today is the labor relations - union contract problem

both as it affects the Quality Control and Inspection department labor force, and as it affects the production labor forces. Generally, labor relations policies have evolved over many years of solving immediate poblems around the conference table and problems of effective quality control have not been weighed very much at such negotiations. This has resulted in leaving many a quality manager's hands tied when it comes to using quality control techniques which others successfully use.

Another factor which greatly affects the quality control picture is the nature of the business. Identical products manufactured by two separate companies may very well present entirely different quality control problems due to differing company policies that apply to inventory control, purchasing, tooling, time study, methods, customer relations, service policies, interaction with other products, plant facilities, etc. In short, any and every difference between the two companies to a greater or lesser degree changes the quality control picture.

I have listened to many lectures and speeches expounding the merits of statistical quality control as I am sure many of you have. With few exceptions the speakers tried to get across the idea that the stock answer of the uninitiated, which is "Sure it works for you, but my business is different", must be brushed aside. Always the effort is expended in trying to prove that correctly applied statistical control techniques will work in any situation.

As I see it, there is a certain amount of truth in both claims. Statictical control techniques will work if sufficient changes can be made but usually when an individual says "my business is different", what he actually means is the changes that will be required to make your system work in my business are greater than the gain that can be made will justify.

I believe that if in our American Society for Quality Control meetings, we would spend more time exploring the affects of outside factors on our quality control problems and in pooling our information as to how such outside factors can be changed, modified, or circumvented, we would then be able to more quickly reap the benefits of statistical quality control techniques.

Much technical information is now available and while new developments will surely follow, progress will be much faster if the problems of practical application of statistical control are first solved.

I believe that a lot could be gained by group discussions of such topics as -

"How do labor relations policies affect quality control"
"What are the affects of incentive plans on quality control"
"How can quality control engineers assist the design engineer"
"How can quality control engineers assist the tool designer"
"How can quality control engineers assist the purchasing dept., or the sales dept., or the service dept."
"How can overall team work for quality be developed"

Quality control is an economic necessity and statistical quality control is an effective management tool. It becomes most effective when the fact is recognized that quality control is not an end or goal in itself, but is only a means to an end. A successful quality control program is a means to more production, less scrap and rework, better labor relations, sustained high quality and a means to reduce administrative problems thus

permitting supervisory and management talents and effort to be utilized for industrial progress.

I have spent most of my allotted time on the broader aspects of quality control because I believe that if I can set you to thinking thus about quality control in the end you will benefit more than as if I tried to in a few minutes explain what we at Scintilla are doing in quality control. Of one thing I am sure, we do not have all of the answers. I will explain one technique we have used effectively, and while I can not give you the mathematical proofs of why it works I can assure you that at Scintilla it has solved a problem.

About two years ago we were faced with controlling the thickness of plating on a group of small parts where the usual quality control approaches did not give the desired results. We manufactured these parts in fairly large quantities.

The parts were made from tellurium copper rod in various sizes from about 3/16 to 3/8 of an inch in diameter and the parts were all about 1-1/2" long. Several undercuts of various widths and diameters were turned on the parts, and each part has a diameter for about 1/3 the length of the part which is held a 50 microinch finish and ±.0008 on the diameter. This is the critical dimension.

The finish for these parts is silver plating and the specification requires not less than .0002 of silver plate and not more than .0004 of silver plate. If insufficient plate thickness exists the parts will not satisfactorily meet electrical and corrosion resistance requirements. If too great a thickness of plate exists the parts will not only cost more than they should to produce, but would fail to assemble in the extreme tolerance conditions. Even if a drop test of the silver plate thickness were feasible the individual parts are too small for accurate drop test measurements; and as the base metal is non-magnetic, the magnetic type of plating gage can not be used. The parts were barrel plated which created the problem of trying to identify individual pieces for measurement. Short cylinders of the same material cut from the bar stock were tried and while these were easy to pick out the tumbling action was such that the plate thickness was not representative of the thickness of the plating on the actual parts. Inspection rejections showed both oversize and undersize parts, and we ran into the usual shop problem of placing responsibility, as the Plating Room claimed that the Automatics Dept. was not holding the size before plating; and the Automatics Dept. blamed the Plating Room for leaving the parts in the cleaning solution too long in the case of undersize parts, or putting too much plate on in the case of oversize parts.

An investigation by the Quality Control group was undertaken.

First - the machine capability for each of the three automatics producing this part was established. One machine was repaired after which all three machines showed a capability of holding a .0003 spread on any one bar of stock; however, an additional variable existed between bars due to bar straightness, diameter variations, and hardness, which introduced another .0003". As this total spread was .0006" while the total tolerance was .0016", control charts were instituted at each machine. This resulted in increased output of product due to less machine adjustment and down time for tool changes. Operator bonus was higher and what was most important, all product was within tolerance.

The plating group had followed the results of this investigation closely and were quick to point out that their previous contention that off dimension parts were the fault of the automatics had been justified. Their victory was short lived however, as final inspection still found parts both oversize and undersize. So now the investigation moved into the plating processes.

Theoretically, plating techniques should be controllable so that any desired plate thickness can be consistently produced. Practically, many variables exist. However; the psychological effect on the plating personnel of being able to see that all parts are within specification and their measurement known, and that off spec. parts after plate would be charged directly to them had a decided effect on the quality of plating.

This led to the procedure of making a frequency distribution of a representative sample of the lot of parts to be plated and forwarding it to the plating room with the work.

It was but one step from this to a frequency distribution of a representative sample of the lot after plating and comparison of the two distributions to determine plate thickness.

A further refinement led to the development of the form in Fig. 1 on which both distributions can be plotted.

The scale is entered in the middle column by averaging the measurement of the first five pieces and setting this value in the heavy outlined cell and then increasing and decreasing from this value in steps of .0001". The reason for this is to center the distributions on the sheet.

A check mark is made for each piece in the sample opposite the appropriate size value. This results in a frequency distribution of the lot. The "before plate" distribution is plotted in the left hand squared area in the reverse of normal procedure to keep the check marks closer to the scale and thus reduce clerical errors. The "after plate" distribution is plotted in the right hand squared area.

The form travels with the lot of work from inspection to plating where it provides the information as to the quality of the lot.

The "after plating" distribution is plotted by a patrol inspector in the plating room and the work is not accepted unless the distributions indicate the correct plating thickness. It is necessary that the same sample size be used after plating as before, otherwise the spreads can not be justifiably compared.

A comparison of the two distributions is made. The offset or difference in the averages of the distributions indicates twice the average plate thickness since all measurements are on the diameter. We have not found it necessary to figure out the mathematical average. We have standardized on a sample size of 75 pieces and we assume the average to be where it leaves half of the sample checks on each side of the line. This offset should be between .0004" and .0008" or 4 to 8 cells. The similarity of the distributions and the spread or range is indicative of the uniformity of plating thickness. As will be noted in Fig. #1, a slight increase in spread is normal and the extent of the increase is indicative of the variation of the plating thickness. For the plating specification discussed in this problem the difference between the spread of the two dis-

tributions should not be less than zero or more than .0004" or 4 cells.

Incidentally, successful application of this method requires some one dimension on the part which is held to close tolerances so that frequency distributions can be formed with a reasonable sample size while the cell divisions can be in tenths of an inch. The total tolerance therefore on the part dimension chosen should not exceed .002. It is possible by increasing the cell divisions to .0002" to .0003" to permit choosing a dimension with a larger total tolerance; however, it is not recommended as the nearer the cell size approaches the thickness of plate, the less the offset, and the less the spread difference will be so that analysis of the results is less and less accurate.

Several million parts in each of eight or nine sizes have been produced under this type of control. A running control chart for size kept at final inspection indicates an average percent defective of .00031 and the defectives are not more than .00015 outside of limits.

In closing, again let me say that Quality Control is not the goal, but only a means to increased industrial accomplishment, and as such is effective to whatever degree it assists in promoting industrial progress.

PLATING THICKNESS CONTROL

Part No. 10-33811 Part Name Elec. Conn Pin Lot Size 2,000 Date 7-7-51

Spec. Before .0619 ±.0008 Inspector No. 99-6794 Spec. After .0625 ±.001 Inspector No. 99-758

BEFORE PLATE AFTER PLATE

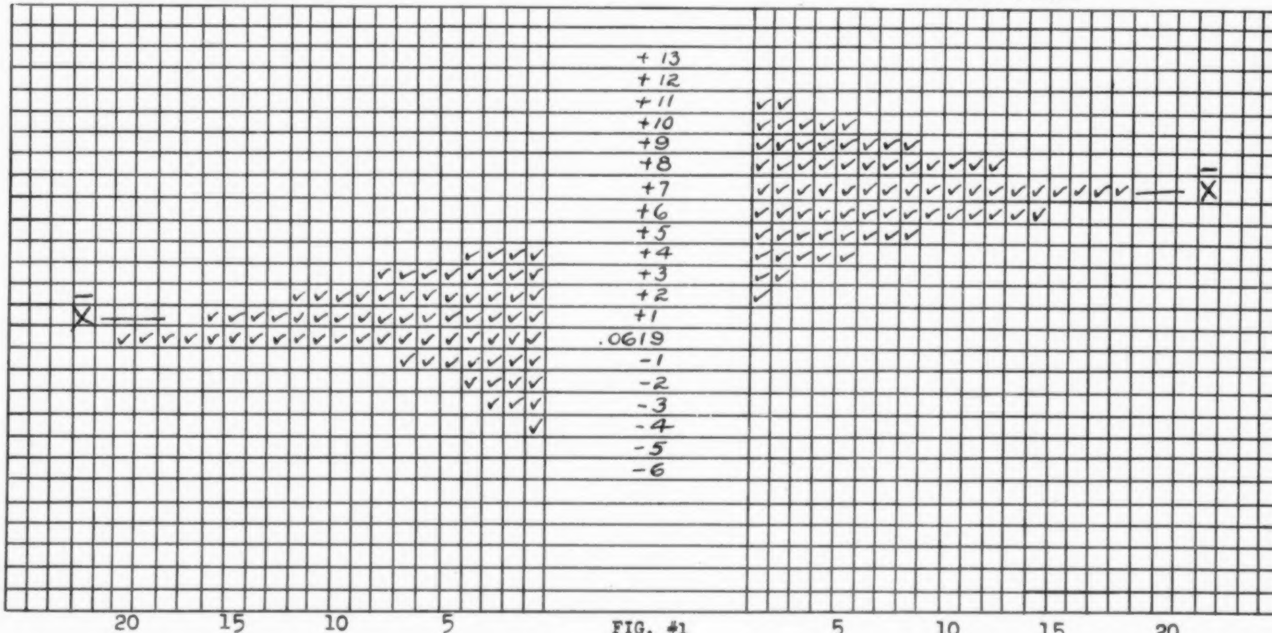

FIG. #1

THE STATISTICAL APPROACH TO BULK SAMPLING PROBLEMS

B.H.Lloyd
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Possibly one should attempt at the outset of a paper which appears under a rather nebulous title, to outline briefly his method of attack, because if this does nothing else, it might save enthusiastic readers from proceeding further and suffering disappointment. There are many optimists eagerly pursuing this panacea of bulk sampling problems up the trail of hope. There are others, and we can speak only of optimists, who diligently absorb what fragments of useful information they can glean from any piece of literature that they can find on the subject. This paper is for those who are not too easily disappointed.

We should all have learned by now from close association with our mathematical colleagues, those of us who are fortunate to have them, that the only completely satisfactory approach to problems which incorporate tangible variables is that which is based on a plan or model. This does not mean that we try to fit the problem to the model, a common enough practice, but rather that we search for a suitable mathematical model which we hope can duplicate the behaviour of our variables at least reasonably well.

It is unfortunate that there is not available at this time a general solution to all bulk sampling problems and it is doubtful that there ever will be. There have been, however, some very commendable attempts to define the problems (1), (2), and noteworthy approaches to specific kinds of problems have been made (3), (4). This paper is an attempt to contribute a little more thought on one specific classification of bulk sampling problems. The classification of which we speak here is that which deals with bulk materials consisting essentially of particles produced in a chemical process which are supposed to have the same ultimate composition. The problem attached to this classification is threefold (i) the determination of the quantity of a sample unit, (ii) the number of sample units for a given precision of quality estimate, and (iii) the investigation of the causes of variation. In the example discussed throughout, the first two considerations are not emphasized as much as the third, because of the limited scope of this paper, and the relative importance of the analysis of variance in studies of this nature.

In the manufacture of mineral fertilizers apatite is one of the commonest sources of phosphate. Apatite in its native form is not soluble as plant food and although ground apatite placed on the land is made available to plants through chemical action with humic acid and carbon dioxide in the soil, the conversion is a slow process. This is overcome by intimate mixing of ground apatite or phosphate rock with sulphuric acid which converts most of the insoluble tri-calcium phosphate into the citrate soluble phosphate of superphosphate available to the plants. The fresh superphosphate produced in this way is stored in a large pile until the chemical reaction has virtually reached completion. The extent of the availability of the soluble phosphate determines the quality of the superphosphate and its commercial value. The flow diagram, Fig.1, shows the various stages in the processing of superphosphate using the Ober method of manufacture. It might be remarked here, for those who are not familiar with the methods of superphosphate manufacture, that the Ober process is entirely enclosed, phosphate rock dust and

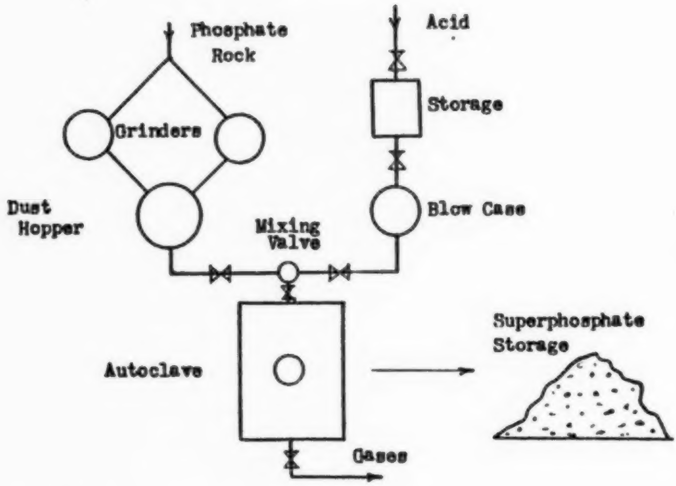

Fig.1 Superphosphate Process Flow Diagram

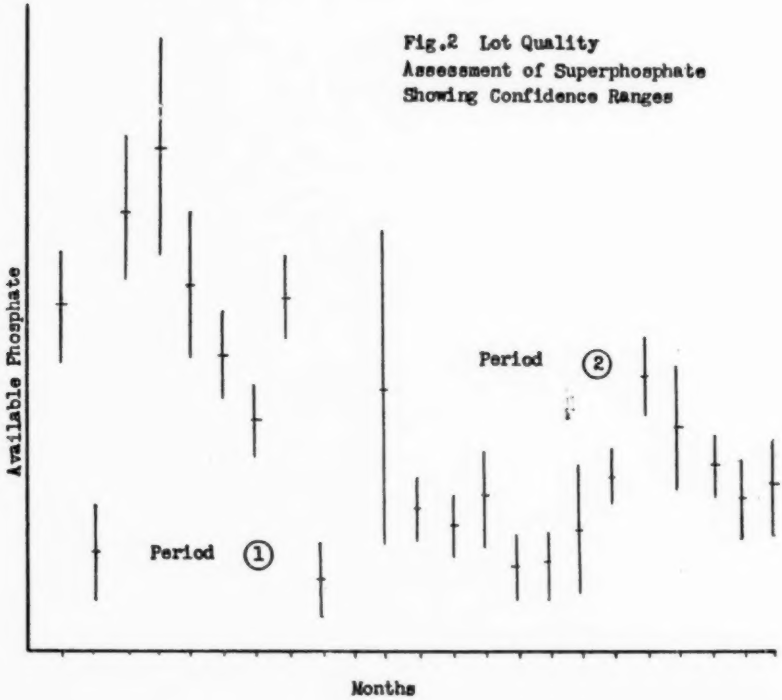

Fig.2 Lot Quality Assessment of Superphosphate Showing Confidence Ranges

acid passing through a mixing valve to an autoclave where the pressure and heat of reaction help to bring about conversion and produce a product dry enough to be discharged without unreasonable delay. Depending on the degree of dryness of the discharge, the superphosphate may consist of large putty-like lumps or fine grain like free flowing particles. This latter consistency, known as pebble superphosphate, is preferable from the standpoint of both producer and consumer and commands a higher price. In storage, the superphosphate is allowed to cure for several weeks, which in effect brings the percentage available phosphate to the high quality level required for compound fertilizers. Batches of superphosphate are not kept separate in storage but it is possible to approximate fairly closely the elapsed curing interval for a particular day's production by noting the location in the storage shed since a systematic method of piling is used.

Disposal of the cured superphosphate is divided between the producer who uses it in the manufacture of his own grades of compound fertilizer and the consumers who are compound fertilizer manufacturers themselves. Theoretically, to provide consumers with a quality estimate of their own shipment, it is necessary to assess the quality of each shipment. This practice is costly and through various studies an attempt is being made to provide a less costly and equally serviceable system of quality assessment.

The importance of selecting a system which will give a high precision to the quality estimate cannot be overstressed as the price of shipments depends entirely on the quoted value of the available phosphate and customers are sensitive to invoices which appear to overestimate the quality of the shipment.

The limitations encountered in sampling problems which fall into this classification are aptly summarized by Deming (2). Selection of samples cannot be made independent of the human element because the material is not divisible into identifiable units and bias, deliberate or unconscious, occurs quite frequently when selection is left to the human being. One could academically anvisage the pile contained entirely in a great number of quart sealers which have been filled as the material enters storage and segregated according to batch and day. The human error in sampling shipments could be practically eliminated under these circumstances and a satisfactory system of quality assessment attained. This idea can be approached in practice where a conveyor belt is used for loading, where the belt is not excessively long. Although the sample units are not identifiable in the strict sense, strips can be marked off across the width of the belt and numbered. Using a table of random numbers, the strips to be sampled can be designated prior to loading and the material constituting the sample unit scooped off if the belt is running slowly enough.

Another system virtually independent of the speed of the belt involves dividing the loading time into a number of equal intervals and selecting the sample on a random basis. At the appointed time, a container placed at the end of the belt removes a cross section which forms one unit of the sample. The quantity of material removed in one unit generally depends on the size and quality of particles of the material. In sampling mineral ore, for example, one large lump could seriously misrepresent the lot if the sample unit were not relatively large. Superphosphate is passed through about a nine mesh screen before loading,a large percentage of the material having the consistency of sand. A cross section of

the loading belt has a concentration of fine material in the center with coarser material on the outside uniformly distributed along the length of the belt, which significantly reduces the probability of particle bias. The laboratory sample is selected as a representative portion of the sample unit after it has been ground and thoroughly mixed.

In sampling superphosphate, the sample unit used at present is large enough to suppress the effect of particle bias and small enough to be easily handled.

The frequency of sampling selected to satisfy a given precision of quality estimate is subject to more capricious effects than the selection of the size of the sample unit. Since the quality estimate here can be permitted only a small deviation from the true quality, cost is not altogether the determining factor in choosing the sample size (the number of sample units in a sample). The variation among sample units within a shipment is the guide to the sample size. It should be mentioned that this is not the case in sampling compound fertilizers where the amount of variation and the within shipment pattern must both be examined. In shipments of bulk superphosphate, the variation is inclined to be large but there is no indication of a non-random pattern at the point of loading over fairly short periods of time. The crux of the whole question of sampling here is what is happening to the variance, but before we can speak of the variance, we must have a definable universe. The universe envisaged here is the cured superphosphate shipped over a given period of time. If the period of time is long, the universe can and does continually change, in position and spread, under the influence of many effects.

It could be demonstrated in this paper, if space permitted, that effects exist in the manufacturing process which appear as significant factors today, but tomorrow lapse into the shadow of random error, to appear again apparently voluntarily sometime in the future. If there are many of these unpredictable flyers in the process, the variance is unstable and the problem of standardizing a sampling scheme is extremely difficult. If the unpredictable effects are few, it is at least possible to obtain, with reasonable precision, some idea of the behaviour of the variance.

Possibly the first and most important step towards the development of a satisfactory sampling scheme is to obtain control of the universe variance. In a reasonably well controlled continuous process, the universe selected for sampling may be quite large, but where possible, the universe should be selected to contain a system of effects which may be considered random for all intents and purposes. For example, superphosphate is normally allowed six weeks cure, but when inventory runs low, it is sometimes necessary to use five week super. If insufficient care is taken, the change takes place during the sampling of the shipment. Here an effect will have been introduced which has virtually produced a new universe. The size of the universe should be such that the system of effects, even though not entirely random, should at least not be changed deliberately within the universe. A continuous unavoidable change in available phosphate would, of course, make this impossible, but under such circumstances, particularly where the change is sharp and takes place over a relatively short period of time, the size of universe sampled should be the size of the smallest shipment.

Fig. 2 shows two periods, the first a period of instability, the second a period relatively controlled. The vertical lines represent confidence ranges and it is readily apparent that some quality estimates of the first period are not as precise as those in the second. In this case, the lots which have been poorly assessed have been too large and have included effects which properly should have appeared in another lot. In quality control language, these lots are not rational subgroups.

Occurence of periods such as those exhibited in the first period of Fig.2 are not infrequent and have led to a number of process studies. Sampling of the lots (Fig.2) may possibly have been made without careful consideration of proper proportions of large and small particles in samples. Could this have been a factor in the variation among sample units. In addition, inconsistent operational factors among batches of superphosphate might have contributed to the apparent instability within and among lots.

One statistical experiment carried out on the superphosphate manufacturing process to answer such questions is described here (9). The experiment was designed to examine the relative contribution to variance of the effects of operational inconsistencies from batch to batch; between particle size groups, viz., fine and coarse; sampling error within batches and analytical error. The quality characteristic chosen for examination was, for chemical reasons, not the available phosphate, but some related characteristic which we will designate by the letter A.

The simple linear mathematical model chosen is expressed as follows:

$$X_{ijkm} = \mu + \alpha'_i + \beta'_j + \gamma'_{ij} + \varepsilon'_{ijk} + \lambda'_{ijkm}$$

Where X_{ijkm} is the m^{th} replicate observation of the k^{th} sample unit of the j^{th} size group of the i^{th} batch and where

α'_i is the batch to batch effect.

β'_j is the size group effect.

γ'_{ij} is the normally distributed batch x size group interaction effect.

ε'_{ijk} is the normally distributed effect among sample units due to within batch heterogeneity.

λ_{ijkm} is the normally distributed effect of analytical inconsistencies.

α'_i, β'_j, γ'_{ij}, ε'_{ijk}, λ'_{ijkm}, are distributed independently of each other and have zero means.

Let the variance components be

$V(\alpha'_i) = \sigma'^2_1$ estimated by s_1^2

$V(\beta'_j) = \sigma'^2_2$ estimated by s_2^2

$V(\gamma'_{ij}) = \sigma'^2_{12}$ estimated by s_{12}^2

$V(\varepsilon'_{ijk}) = \sigma'^2_3$ estimated by s_3^2

$V(\lambda'_{ijkm}) = \sigma'^2_4$ estimated by s_4^2

$n_1 = 9$ = number of batches.

$n_2 = 2$ = number of size groups.

$n_3 = 4$ = number of sample units per size group per batch.

$n_4 = 2$ = number of replicates.

ANALYSIS OF VARIANCE BREAKDOWN

Description of Effect	Degrees of Freedom	Mean Square Estimate
Among Batches	n_1-1	$n_2n_3n_4s_1^2+n_3n_4s_{12}^2+n_4s_3^2+s_4^2$
Between Size Groups	n_2-1	$n_1n_3n_4s_2^2+n_3n_4s_{12}^2+n_4s_3^2+s_4^2$
Batch x Size Group Interaction	$(n_1-1)(n_2-1)$	$n_3n_4s_{12}^2+n_4s_3^2+s_4^2$
Sampling Error	$n_1n_2(n_3-1)$	$n_4s_3^2 + s_4^2$
Analytical Error	$n_1n_2n_3(n_4-1)$	s_4^2

TABLE I

CODED VALUES OF A

Batch	Size Group							
	Fine				Coarse			
1	95 73	92 69	113 100	60 59	20 26	95 104	96 96	68 71
2	142 129	131 105	71 82	88 109	150 148	160 166	60 60	111 88
3	81 117	109 112	138 91	105 107	111 111	114 121	150 102	155 132
4	106 100	39 – 2	89 101	114 113	105 82	67 85	192 137	140 168
5	129 125	108 68	79 38	89 113	142 128	98 118	141 113	99 113
6	39 102	119 128	39 23	38 71	122 145	16 73	– 29 – 30	79 77
7	88 102	65 70	107 109	93 95	36 29	69 70	161 109	140 135
8	100 100	92 108	169 153	136 130	131 133	54 82	138 171	154 170
9	67 68	87 91	87 88	87 104	36 50	135 54	102 70	137 130

TABLE II

ANALYSIS OF VARIANCE

Description of Effect	Degrees of Freedom	Sum of Squares	Mean Square Estimate
Among Batches	8	48002	6000.25
Between Size Groups	1	2934	2934.
Batch x Size Group Interaction	8	9716	1214.50
Sampling Error	54	136709	2531.65
Analytical Error	72	21931	304.59
Total	143		

Testing the effects in Table II for significance at the 95 per cent level using the F ratio, we have -

Among Batches $F = \frac{6000.25}{2531.65} = 2.37$

$F_{.05} \doteq 2.11$ for 8 and 54 d.f.

Between Size Group $F = \frac{2934}{2531.65} = 1.16$

$F_{.05} \doteq 4.02$ for 1 and 54 d.f.

Interaction $F = \frac{2531.65}{1214.50} = 2.08$

$F_{.05} \doteq 3.03$ for 54 and 8 d.f.

Note that the F ratio for the interaction effect here tests for a significantly small effect as the batch x size group interaction mean square is less than the sampling error mean square.

For the among batch effect we draw the inference that σ'^2_1 is not zero. However, it appears that the between size group effect and the batch x size group interaction effect have zero variances, that is σ'^2_2 and $\sigma'^2_{12} = 0$.

Working out the variance component estimates -

$$s_1^2 = 217.$$

$$s_3^2 = 1114.$$

$$s_4^2 = 304.$$

It would seem from these results then, that if we were to perform single analyses on sample units taken at random from the superphosphate process irrespective of batches or size groups, that by far the greatest source of error among the observations should be attributed to heterogeneity within the batches. As a matter of interest, it was suspected prior to the experiment, that the greatest source of error would occur among batches and that the between size group effect would have a relatively large variance.

From a purely technical standpoint there is quite good reason to suspect heterogeneity within batches since intimate mixing of the phosphate rock dust and the acid which are forced under pressure into the autoclave, is not a simple achievement, particularly as the control valves are opened and closed by the operators. The result of this experiment carried enough strength to justify a research project on primary mixing of acid and rock dust.

An inspection of the analysis of variance table might give rise to some wonder at the relative sizes of the batch x size group interaction and the sampling error mean square. Whether or not a fair degree of batch bias was expected to influence size groups it appears that the sampling error is larger than the interaction effect although not significantly so. There is every indication that an additional experiment should be carried out.

The fact, however, that the particular mathematical model chosen to fit this experiment may not have been appropriate in all aspects, is something which must not be overlooked. For example, it cannot be rigidly assumed that sample units are independent of one another, since acid in excess at one spot in the autoclave must mean a deficiency of acid in another, and each sample unit of phosphate rock has not had an equal chance of exposure to its allotment of acid. This virtually means that the sample units are correlated which would account for a large within batch variation and provide an invalid basis for assessing the batch and size group effects.

Statistical experiments such as the one just described above might seem by some to be a little out of line with problems of bulk material sampling but possibly not when it is considered that sampling depends so largely on the behaviour of the variance. For example if we take the above experiment at its face value the variance of the cured superphosphate could attribute much of its

size to inadequate mixing of phosphate rock and acid in the autoclave and not to the inconsistency of operation occuring among batches. Were it possible to retain the identity of the batches during the curing period estimates of components of variance within and among batches would be necessary in selecting the number of batches to be sampled and the number of sample units per batch. A course such as this is followed in the U.S.Customs (3). In addition it might be pointed out that although superphosphate particles of various size classes do not appear to be correlated with quality, DeLury (5) has offered a method of sampling material where quality trends are exhibited, for example across a conveyor belt where the higher density particles seek the lower levels of the strip and a pattern is effected.

For normal superphosphate shipping periods the variance among sample units taken at random over a period of about a week appear to reflect about the same variance as that estimated over a much smaller period say an hour or so. In other words conditions do not voluntarily change appreciably over a period of a week's time. Changes which do appear, apart from occasional inexplicable irregularities, are gradual trends in raw material quality and more frequently understandable misjudgment of the degree of cure of superphosphate by the crane operator in the storage warehouse.

On the basis of assessing the quality of collective shipments over the period of a week which is virtually stable it follows that the weekly average gives as precise an estimate of any portion of the weekly shipments as would the average of the same number of sample units from that portion. This obviates the necessity of assessing each shipment individually. Early practices favoured compositing sample units for the period over which the quality assessment was desired but this has been modified for obvious reasons, one being that no running check is available on the variance.

In all sampling schemes we must tolerate a risk which is the probability that the true average quality of the material sampled does not lie within a fixed range about the sample mean (6). In quality control circles this is known as the consumer's risk. For example sampling specifications might read "The number of sample units must be such that the true average quality of shipments made during the week shall lie within $\pm$ 0.05 available phosphate about the sample mean with the concession that only 5 out of 100 times may these limits be violated." In statistical language these limits are known as 95 per cent confidence limits.

Let us assume that repeated sampling of weekly shipments of superphosphate give analyses of available phosphate which are more or less normally distributed, with a standard deviation of 0.187. How many sample units should be taken per week to assure with 95 per cent confidence that the true average quality of a week's shipments lies within the limits of $\pm$ 0.05 about the sample mean.

Using normal distribution theory we have

$$N = \left(\frac{k\sigma'}{.05}\right)^2 = \left(\frac{1.96x0.187}{0.05}\right)^2 = 54$$

This same result can be arrived at using Tanner and Deming's formula (4).

$$N = \frac{(t.V_x)^2}{E}$$

where t is equivalent to k above = 1.96

V_x = coefficient of variation = 1%

E = allowable uncertainty of the sample mean = 0.0025

$$N = \left\{ (1.96) . \frac{(0.187/20)}{(0.05/20\ )} \right\}^2 = 54$$

It matters very little what formula is selected as long as the essential basic concepts are taken into consideration.

Assuming that 54 samples are necessary to give the required precision of quality estimate it was suggested earlier that a modified form of compositing might be used to cut down on analyses and still provide an estimate of the sampling variance. If the laboratory error, which consists of both analytical and laboratory sample-preparation error, is $\sigma_a'^2 = 0.005$ what is the most economical number of composite samples and replicate analyses in keeping with the desired precision of the quality estimate.

$$\sigma'^2 = \sigma_s'^2 + \sigma_a'^2$$

$$\sigma_{\bar{\bar{x}}}'^2 = \frac{1}{m} \left\{ \frac{\sigma_s'^2}{n} + \frac{\sigma_a'^2}{r} \right\}$$

Where $\bar{\bar{X}}$ = average of composite samples.

σ'^2 = universe variance.

$\sigma_s'^2$ = sampling error variance.

$\sigma_a'^2$ = laboratory error variance.

m = number of composite samples.

n = number of sample units per composite.

r = number of replicates per composite.

Given $\sigma_s'^2 = 0.030$ and $\sigma_a'^2 = 0.005$ values of m, n and r must be selected to comply with $1.96\ \sigma_{\bar{\bar{x}}}' \leqq 0.05$ or $\sigma_{\bar{\bar{x}}}'^2 \leqq$ 0.000651.

It follows that $\frac{1}{m} \left\{ \frac{\sigma_s'^2}{n} + \frac{\sigma_a'^2}{r} \right\} \leqq 0.000651$

The minimum number of sample units necessary has been found to be 54 but it is obvious that irrespective of how we break this down into composites the total number of analyses must be 54 to meet the precision requirements.

For example if we divide the 54 sample units into say 6 composites of 9 sample units each although only 6 samples are submitted for analysis 9 replicate analyses must be obtained for each sample in order to comply with precision requirements. If we are limited to 54 sample units the most economical scheme is one analysis for each of the 54 samples.

With no limit on the number of sample units the most economical combination of m, n and r depends entirely on the cost of sampling and analyzing. A somewhat similar problem is discussed by Brownlee (7) who has computed a table of the optimum number of analyses per sample for given values of $\sigma_s'^2/\sigma_a'^2$ and the ratio of cost of sampling to cost of analysis. By "optimum number" he has in mind the number of replicates to give the minimum variance for any total expenditure where a linear relation exists between the cost of analysis and cost of sampling.

TABLE III

TOTAL COST OF COMPOSITE SAMPLING AND ANALYSES

$\sigma_s'^2 = 0.03$, $\sigma_a'^2 = 0.005$, Precision of $\bar{\bar{X}} = \pm\ 0.05$

Equation $m = \frac{46.1}{n} + \frac{7.68}{r}$

r	m (rounded)	n	C
1	13	10	23.2
	12	11	22.3
	12	12	23.3
2	6	20	18.6
	6	21	17.3
	6	22	17.7
3	7	13	17.2
	6	14	15.3
	6	15	15.8
4	5	21	17.2
	4	22	14.0
	4	23	14.4
5	4	30	18.7
	3	31	14.4
	3	32	14.8

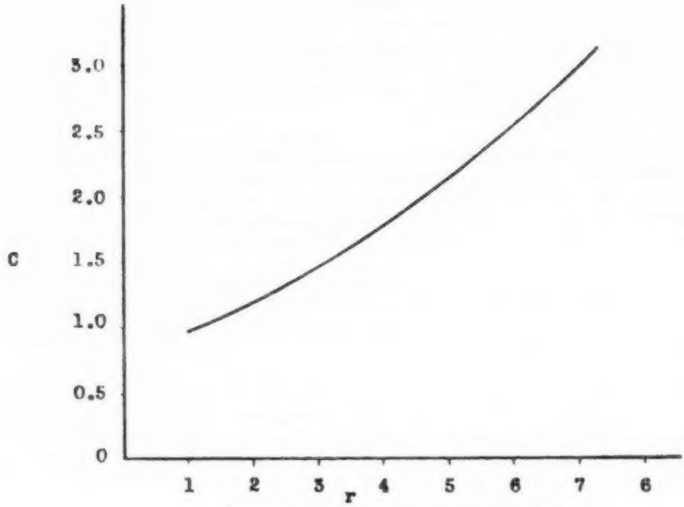

Fig.3 Cost of Replicates Per Sample.

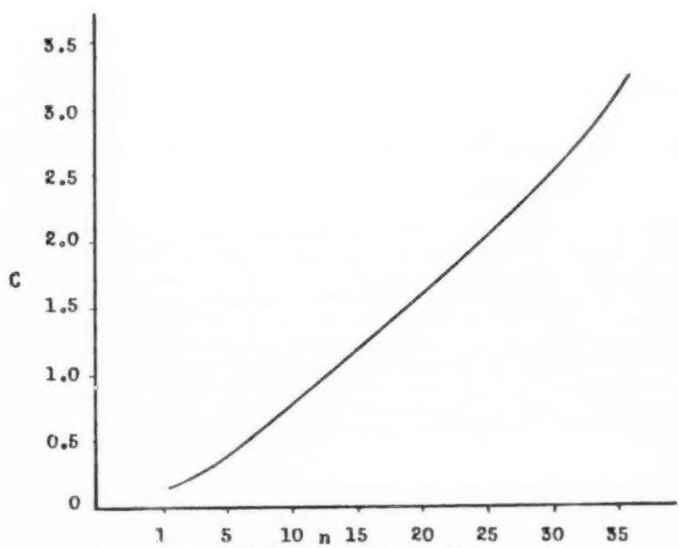

Fig.4 Cost of Preparing a Composite
Sample of n Sample Units.

An additional variable, m , is added in this problem and a non linear relation exists between costs, Figs.3, 4, but the general solution to this can be found easily with knowledge of the equations of the cost curves. Fig. 4 gives the cost of preparing a composite for a given number of sample units. Fig. 3 gives the cost of replicates per composite sample.

The cost of preparing and analyzing a composite must be multiplied by the number of composites to give the total cost. Table III gives total costs for various values of m, n and r. For a given value of r there are values of m and n which give a minimum cost for the set but when r = 4, m = 4, n = 22, the total cost is a minimum.

It is seen, therefore, that 4 composites of 22 sample units, each with 4 replicate analyses is the most economical plan for the required precision. The total number of sample units necessary is 88 and 16 analyses must be made in all.

Finally we make some provision for checking the sampling error variance from week to week. This can be done in a number of ways the simplest of which is perhaps by plotting the sampling error standard deviation of composite averages on a quality control chart. From $\sigma_s' = 0.173$ the two sigma limits for $\dfrac{\sigma_s}{\sqrt{n}}$

where n = 22 and $c_2 = 0.966$, (8), are

upper limit	=	0.046
lower limit	=	0.026
central line	=	0.036

Plotting values of $\dfrac{\sigma_s}{\sqrt{22}}$ on this chart we are taking about a 5 per cent risk of revaluating σ_s' when in actual fact σ_s' has not changed, if the process is stable.

These thoughts put into practice have provided a fairly satisfactory sampling system for bulk superphosphate. Although many of the details are applicable only to this process it is not the details about which we should be concerned when examining a specific case but the ideas themselves. The details should be arrived at through common sense. What we wish to have is a stable variance of unassignable random causes within the universe to be sampled. If effects are present apart from this so-called error then they must be controlled in such a way that their contributions to variance are measurable. It is for this task that we have the mathematical model and the statistical technique.

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NARROW LIMIT GAGING

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1. Introduction. The advantages which are inherent in a program of Quality Control require an appreciation of its philosophy, an understanding of its techniques, and provision for competent management of the program.

The discussion in this paper will center about the use of gages to guide a process. Although this is a technique, it has already touched upon philosophy--the importance of preventing trouble rather than waiting until after manufacture to weed out the most inferior items. And it has implied the importance of management in the quality control program; the process can be guided only if information from the gaging (or inspection) function is made available to production--in time to prevent the manufacture of subsequent defects.

A basic technique of modern quality control is the Shewhart control chart for variables. One reason for its importance is the sensitivity obtainable from averages of small samples (of measurements) in comparison with an inspection record obtained from Go-No Go gages (attributes). The rate at which the use of these Shewhart control charts is being recognized is accelerating rapidly; yet even so, the rate is much slower than justified by economic possibilities. Some industries have made important applications--others are interested, but hesitant.

There are different reasons for the hesitance. For example, gaging to fixed limits often requires less skill and frequently less time than does measurements in certain operations. Then too, the tradition of gaging is a habit which has been established through many years of practice in some shops even where it is entirely feasible to make measurements. In either case, if we are to accelerate the acceptance of process quality control, we must either persuade these shops to make measurements on small samples at appropriate intervals of time; or we must concede that there are real advantages to gaging and develop techniques to improve the sensitivity of Go-No Go data.

It is our personal intentions to use both approaches, and we will make our decisions in terms of the existing traditions and personnel in each plant, and in terms of the type of operations involved. A control chart using X-bar and R is a powerful tool. But we are impressed, too, with the sensitivity which can be obtained with Narrow-Limit Gages (NL-Gages) using samples comparable in size with those for X-bar and R charts. In this paper we discuss some of our experiences with the use of NL-Gages, and indicate enough of the theory to provide a practical basis for applications of the methods.

2. General Applications of Narrow-Limit Gages. A screw-machine shop is a typical example of an operation which can make important applications of statistical quality control. It is our experience that only a few of them have done so; many plants have spent large sums of money for automatic screw-

machine lathes, but have not made adequate provision for controls. Many people are not yet familiar with the economic advantages of using even the straightforward applications of statistical quality control.

There are many operations which use gaging techniques or variations of them. The sensitivity of a destructive test can be modified by the design; a test designed to destroy all of the items tested, or one which will destroy none of the items, does not provide a means of distinguishing between different levels of the two products. The killing of insects by insecticide; biological assay, and similar techniques; the comparison of one taste or smell with another; the comparison of one defect with another; these are all variations of Go-No Go Gaging, and the sensitivity of their applications can usually be improved by appropriate statistical design. The techniques discussed in this paper are pertinent to these objectives.

In some processes the process capability is less than the (specification) tolerances, and economics indicate that some shift in the process average can be allowed--provided we have means of detecting the approach of rejects. In other processes, the process variability is essentially equal to the tolerance spread, and statistical control of the process is necessary (minimum shift in process level) to minimize rejects from the process (See Section 11). The application of NL-Gages will be discussed in reference to both types of applications.

There have been two important papers on Compressed (or Narrow-Limit) Gages, both published in England. We are indebted, particularly, to two articles for many ideas developed in this paper; one article is by Dr. B. P. Dudding and W. J. Jennett (1) and the other is by W. L. Stevens (2).

The contributions of this present paper are presented as the following:

(1) The presentation of families of Operating Characteristic Curves (OC-Curves) of the sampling plans.

(2) There is always a value in presenting OC-Curves with a sampling plan; but we have also exhibited families of these OC-Curves to show the effects of changes in important phases of the NL-Gaging plans. These families of curves are adequate to indicate the choice of a particular NL-Gaging plan in a particular application.

(3) Criteria for selecting an NL-Gage plan.

(4) The use of NL-Gages for Acceptance Sampling.

(5) An outline of the British developments in NL-Gaging (Section 11).

(6) Specific case histories relating to the production application of NL-Gaging techniques (Section 13).

(7) A simple Specific Vendor Instruction Manual for Shop Operations to help vendors set up NL-Gaging plans (Section 8).

3. Outline of an NL-Gaging plan. To guide manufacturing, Go-No Go Gages shall be prepared which are stricter than specifications by an amount which we indicate by the sumbol $t\sigma$ (see Fig. 1). Then small samples (of 5, 10, or 20) shall be taken at regular intervals of time, and a record kept of the number of units which do not pass the NL-Gages. (Any units which fail the NL-Gages, but which pass specification Gages can be sold by the company, of course).

In our initial discussion we will assume that there are two specifications and that they are wide in comparison with the process capabilities. We shall consider that six standard deviations (6σ) represents the process capability.

(Stevens discusses, in great detail, a method of control when the process capabilities are essentially equal to the required tolerances (Section 11).

The NL-Gaging plan is specified by three characteristics:

(1) The sample size, (n),

(2) The number (c) of units (in the sample) allowed outside an NL-Gage before the process is to be adjusted,

(3) The distance ($t\sigma$) which the NL-Gages are moved in from the specifications.

4. Estimate of process capability. Evidently, then, an estimate of the process variability is needed before an appropriate gage can be specified. If there is a control chart history for the (controlled) process, then the evident estimate is:

$$\sigma = \bar{R}/d_2.$$

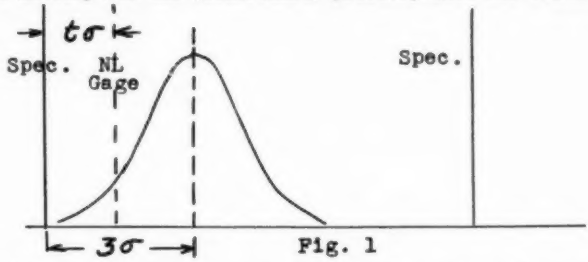


Fig. 1

where d_2 is a constant (3). Or, we may base our estimate of σ on experience either with the particular process or machine; this experience may be personal, or it may be general trade experience (Section 8).

Frequently, a satisfactory estimate of the variability can be established by a conference which includes two or three men who are familiar with the process representing production and engineering. If measuring equipment is available, then they can be used to obtain measurements on a number of items, and an estimate of the process variability. (Special gaging techniques may also be used to provide an estimate of σ.)

5. Operating Characteristic Curves. It is standard procedure to indicate a sampling plan by its average outgoing Quality Limit (AOQL), or its Acceptable Quality Level (AQL), or its Lot Tolerance Percent Defective (p_t). The Dodge-Romig tables list both an AOQL and a p_t. The recently revised Military Standard 105-A (Mil Std 105-A) goes even farther and furnishes Operating Characteristic Curves (OC-Curves) for different sampling plans, and this procedure is to be recommended.

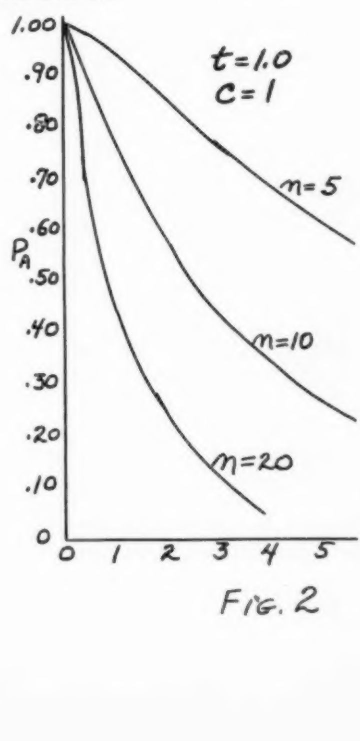


FIG. 2

We present several different families of OC-Curves corresponding to certain variations in the NL-Gaging procedures. The abscissa, p. represents the percent outside of specifications; the ordinate represents the probability of "accepting", or more appropriately in process control, the probability that the process will be allowed to continue without adjustment.

A. Effect of change in n (for fixed values of t and c). Whenever we pick a larger sample from a lot, we expect to find more defectives; an increase in n will evidently increase the severity of our plan unless some other compensation is provided. The extent of this effect of changing n is indicated in Fig. 2 corresponding to arbitrarily selected values of t and c.

B. Effect of change in c (for fixed values of t and n). If we accept more items outside our NL-Gages, the severity of the sampling plan will decrease. The extent of this decreasing effect is shown in Figures 3A and 3B.

C. Effect of change in t. As we increase t we increase the strictness of our NL-Gages and consequently the severity of our sampling plan. (See Figures 4A, 4B, 4C, and 4D.

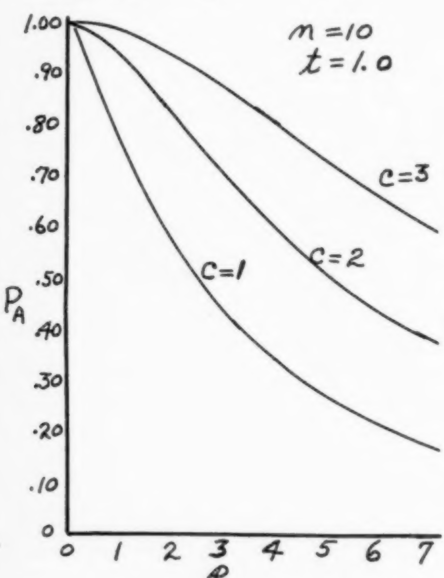


FIG. 3A

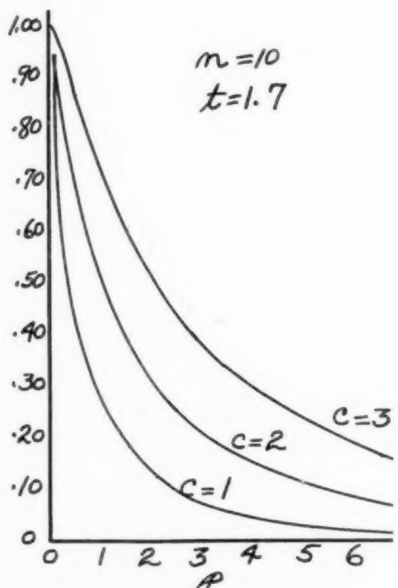


FIG. 3B

Dudding and Jennett designate their gages in the following way. If the gages are moved in 3σ units, then $t = 3$, and the gages are called 50% gages; if $t = 1.7$, they are 10% gages; if $t = 1.5$, they are 7% gages. They are designated by the area between the specification limit and the NL-Gage Limit when the process average is 3σ units inside the specification limit.

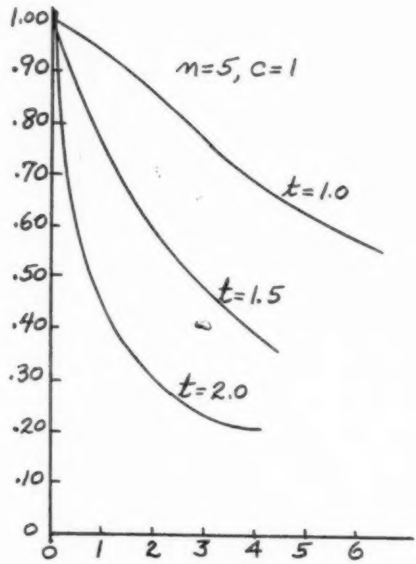


FIG. 4A

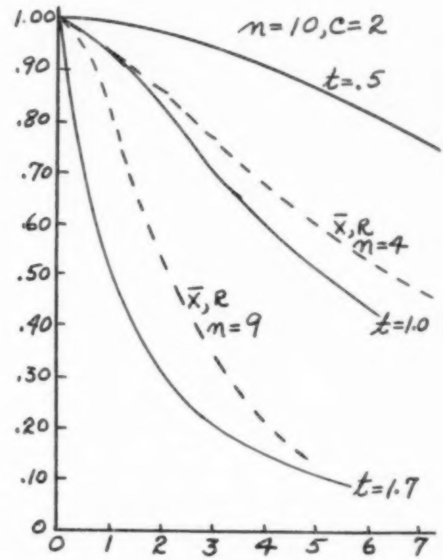


FIG. 4B

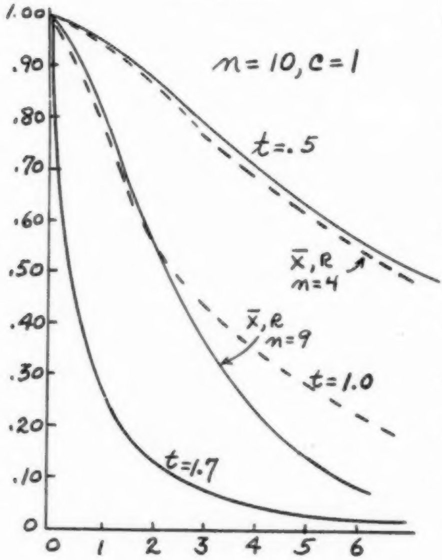


FIG. 4C

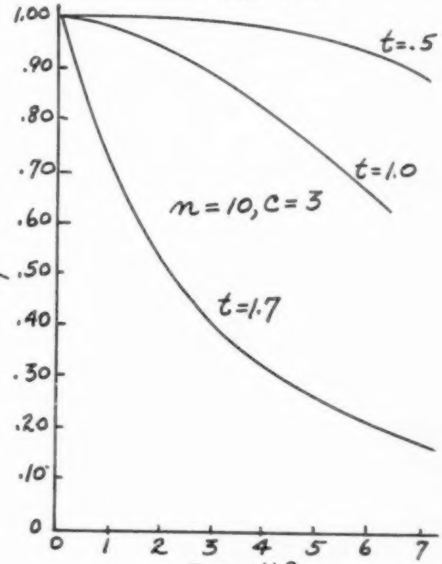


FIG. 4D

6. Selection of a simple NL-Gage Sampling Plan. Most people who have worked in quality control have (sometime or another) used $\bar{X}$, R-charts for sample sizes $n = 4$ or $n = 5$. Personally, we don't usually use larger sample sizes not (even as large as $n = 9$) because they indicate shifts or peculiarities in the process which aren't usually worth looking for.

Criterion A. Then those who are familiar with $\bar{X}$, R-charts, for $n = 4$, will have a sense of familiarity with an NL-Gaging plan which has a similar OC-Curve. Now in Fig. 4B and Fig. 4C, we have indicated (by broken lines) the OC-Curves corresponding to two $\bar{X}$, R-charts. Evidently there are at least three NL-Gaging plans which have OC-Curves almost identical with $\bar{X}$, R-charts for $n = 4$, namely:

$n = 10$, $c = 2$, $t = 1.0$; (Fig. 4B)
$n = 10$, $c = 1$, $t = .5$ (Fig. 4C)
and $n = 5$, $c = 1$, $t = 1.0$ (Fig. 4A).

If we are controlling a process with $\bar{X}$, R-charts with $n = 5$, and we believe there is need for more information, then we usually take samples more frequently in preference to increasing the size of n. The same recommendation applies to the use of NL-Gages, recognizing that different conditions require different solutions.

Criterion B. The effectiveness of any of these techniques in controlling quality is improved when we post the record of our results on control charts. These charts frequently indicate the approach of trouble in time to take corrective action. This indication of approaching trouble would not be possible in an acceptance plan with an acceptance number of $c = 0$; for as soon as even one unit is found outside NL-Gages, the process would have to be reset. Consequently the smallest desirable value of c, for process control purposes, would be $c = 1$.

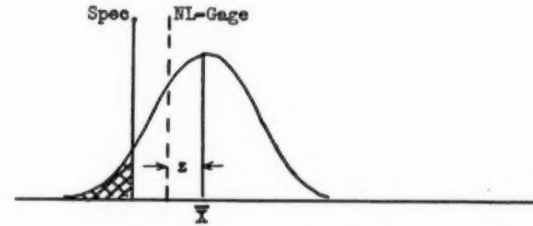
Criterion C. If we are not much concerned about resetting the process unless the process shifts quite a distance, then $n = 10$, $t = .5$, and $c = 2$ or 3 may be an appropriate plan. If, however, it is important to reset the process if there is even a small percent outside of specifications, perhaps $n = 10$, $c = 1$, $t = 1.0$ is indicated. This latter plan is a little stricter than the plan designated by Mil Std 105-A as a 1½% AQL (p. 33, Letter H).

There must always be a compromise between the Producer's Risk (the probability of resetting the process unnecessarily)—and the Consumer's Risk (the probability of not resetting the process when the process has shifted too far). These concepts have been developed by Harold Dodge and Harry Romig (4).

Criterion D. Dudding and Jennett indicate plans with large acceptance numbers; such as $n = 10$, $c = 8$, $t = 3.0$. In many cases there are psychological arguments against such large values of c—it is difficult to convince an operator that he should be "quality-minded" if you tell him that he will be allowed as many as 8 units out of 10 outside the Gage—even an NL-Gage. In such cases, a plan with a small c is evidently to be preferred.

The choice of a large value of t, such as $t = 3$, will in some cases mean that only one Gage set at the process target is needed. In any event, almost identical OC-curves can be obtained by variations of both c and t. (See, for example, $n = 10$, $t = 1.7$, $c = 3$ and $n = 10$, $t = 3.0$, $c = 8$). A single gage set at the desired mean is equivalent to using the median of the sample to estimate the mean of a normal distribution.

TABLE I



Based on Molina's Tables (Poisson)

n = 5
t = 1.0
c = 2

% outside specification	1.0+z	z	P % outside NL-gage	np=sp	Prob. of Acceptance (P_A)	Plan B P_A^3	np=15p	Plan C c = 2	Plan D c = 3	Plan E c = 4	Plan F c = 5
.097	3	2.0	2.27	.113	100%		.339	99.6	100	100	100
.5	2.53	1.57	5.82	.291	99.7	99.5	.873	93.3	98.7	99.8	100
1.0	2.33	1.33	9.2	.46	98.6	96	1.38	83.3	94.6	98.6	99.7
1.5	2.17	1.17	12.1	.605	97.7	93	1.81	73.1	89.2	96.4	99.0
2.	2.05	1.05	14.7	.735	96.0	88.5	2.205	62.3	81.9	92.8	97.5
3.	1.88	.88	18.9	.945	93	80	2.83	46.9	69.2	84.8	93.5
4.	1.75	.75	22.7	1.13	89.5	72	3.4	34	55.8	74.4	87.1
5.	1.64	.64	26.1	1.30	85.7	63.5	3.9	25.3	45.3	64.8	80.1
6.	1.55	.55	29.1	1.45	82.5	56.5	4.3	20	37.7	57.0	73.7
7.	1.48	.48	31.6	1.58	78.3	48	4.74	15.2	31	49	64
8.	1.41	.41	34.1	1.70	75.7	43.5	5.1	11.6	25.1	42.3	59.8
10.	1.28	.28	39	1.95	69	33	5.85	7.	17	31.3	47

Summary: The families of OC-curves given in the accompanying figures are entirely adequate to indicate appropriate choices of n, t, and c; different combinations permit the selection of a plan tailored to the peculiarities of the particular type of industry or operation. OC-curves of $\bar{X}$, R control charts, the OC-curves of Dodge-Romig, or of Mil-Std 105-A will provide a convenient standard of comparison.

For those who like to adjust a sampling plan to fit their own particular needs, a table of computations has been included in the Table. (This particular one is based on the Poisson using Molina's tables (6)).

7. Sequential NL-Gaging Plans. In the preceding section we discussed methods of selecting a simple NL-Gaging plan. But before selection one, it will be worth while to consider the effect of maintaining an accumulated record of the last few lots. For example, although it might be reasonable to allow one unit to be oversize in a sample of 5, it might not be reasonable to permit the process to continue if three consecutive samples contain an oversize unit.

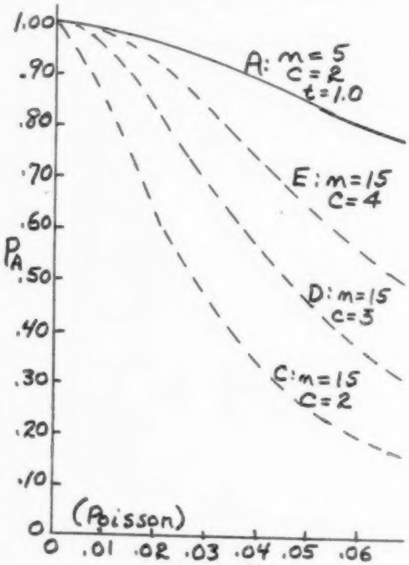


FIG. 5

We have presented certain OC-curves in Figure 5; these are the curves corresponding to the different plans computed in the Table. The OC-curve listed as Plan A corresponds to (n = 5, t = 1.0, c = 2). This is not a very strict plan; we see that it will not work a hardship on production by stopping the process even if the percent of rejects is as high as 3% or 4%. However, it will allow the process to continue about 80% of the time if the percent of rejects is as high as 7% or 8%.

The severity of the OC-curve for larger values of p can be obtained by coupling two plans; for example, Plan A (n = 5, t = 1.0, c = 2) and Plan D (n = 15, t = 1.0, c = 3). The decision to adjust the process will then be made either,

(a) on the evidence of the last sample of 5, or
(b) on the combined data of the last three samples, n = 15.

(Note: The OC-curves shown for n = 15 are slightly more liberal than the OC-curves corresponding to three successive applications of Plan A; since for example, Plan D would permit the process to continue if there were 2 defects in one sample and one in another, and Plan A would not allow continuance because of the 2 defects.) It should be noted that the same NL-Gages are used for the two parts of the sequential plan.

In practice, we have found this accumulation of evidence from successive samples to be of economic importance and easy to administer. Consequently, we have listed other families of curves corresponding to n = 5, 10, 15, and 30, with values t = 1.0, and 1.7, and certain selected values of c. These families may be used as plans in their own right or in conjunction with other plans.

8. Vendor Instruction Pamphlet. We have prepared a booklet, with simplified directions for selecting and operating an NL-Gaging plan, including appropriate record sheets. Although it was prepared primarily for machine operations, it has broad interpretations. Copies are available upon request.

9. Acceptance Sampling with NL-Gages. It should be evident that these plans are eminently suitable as acceptance plans and to be preferred in many operations to gaging to the specifications. (This discussion will be developed in a later paper).

10. Hazards.

(a) There is a potential error if our estimate of σ is incorrect—the extent of the effect can be seen from Fig. 4. If our estimate of σ is in error by 25%, for example, instead of operating on a curve corresponding to $t\sigma = 1.0$, we either operate on the curve corresponding to $t\sigma = 1.25$ (if our estimate of σ was too large) or we operate on the curve corresponding to $t\sigma = .75$ if our estimate of σ was too small. In either case, a difference of this magnitude does not appear to be an important factor.

(b) Suppose that portion of the distribution nearest the specification limit is not essentially normally distributed? In most instances this is more of a statistical question than a practical one—although there are notable exceptions in certain electronic characteristics, for example. We have never found enough variation from a normal distribution in machine operations to be worth mentioning. Although there is an effect from tool wear, that portion of the curve nearest the specification (and from which we draw our sample—the last n consecutive pieces) is typically normal.

If the distribution is "violently" non-normal, or if an error is made in estimating σ the NL-Gaging system still provides control of the process but not necessarily at the predicted level.

In discussing a similar situation, Tippett (7) remarks that there need not be too much conern about whether there was an "accurate and precise statistical result, because in the complete problem there were so many other elements which could not be accurately measured."

11. Control of process to a target. Stevens (5) discusses the control of a process which has a single "hump near the mean" and which is "not violently asymetrical". His technique is to use two gages which are (preferably) equidistant from the mean. He counts the units in the sample of n which are:

	% in sample	number in sample
above the upper gage;	r,	c,
between the gages;	q,	b,
below the lower gage;	p,	a,

He keeps control charts on (c-a) to control the mean of his process; control limits can be obtained from the variance,

$$\sigma^2_{c-a} = n\left\{(p + r) - (p - r)^2\right\}.$$

He also keeps control charts on (c + a) to control the variability of his process. The distribution of (c + a) is given by the binomial expansion of

$$\left\{q + (p + r)\right\}^n .$$

His control charts for (a + c) are valid even if the distribution is not normal, but he advises an adjustment for (c - a). He lists the (statistical) efficiency of different gages as follows:

		Ef(m)	Ef(σ)	Ef(m,σ)
Maximum efficiency of estimation of mean:	p = r = 27%	81%	33%	52%
Maximum efficiency of estimation of sigma:	p = r = 7%	51.5%	65%	58%
Maximum value of Ef(m,σ)	p = q = 13%	69%	59%	64%
Recommended compromise	p = q = 20%	78%	46%	—

12. Control of variability. Many industrial process capabilities show little tendency to change. But if there is doubt about the stability of the process variability, we can make either a regular or a patrol check with a gage set at the specification limit. Then from the recorded percent outside the NL-Gage and outside the Spec-Gage, two simultaneous linear equations can be set up and solved both for and for $\bar{X}$.

13. Case histories. A discussion of two of our experiences will be presented in a later paper. However, we discuss two of them here at the National Convention of ASQC. They pertain to:

(a) the use of a particular NL-Gaging plan to control a screw-machine process, and

(b) the application of NL-Gaging to control a cathode spraying operation in the manufacture of electronic tubes (a hand operation).

14. Part II of this paper will be presented later.

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THE ERROR IN MEASUREMENT

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No measuring process can translate a measurable characteristic of a product into its exact numerical representation. The deviation of the actual measurement (y) from the true numerical value of the characteristic (x) may be called the error of the measuring process (ε). Then $y = x + \varepsilon$.

All conditions remaining unchanged, repeated measurements on the same x will yield a different value of ε for each measurement so that there exists a distribution of such ε's having a fixed mean, u_ε, and a fixed standard deviation, σ_ε. We say that the smaller the magnitude of u_ε, the greater is the "accuracy" of the measurement process, and the smaller the magnitude of σ_ε, the greater the "precision" of the measuring process. The magnitude of u_ε is often referred to as the "bias" of the measuring process.

If the distribution of ε's, described above, is the same, regardless of the magnitude of x, then we say that x and ε are independent. The discussion which follows assumes that this independence exists. This is not the case in some measuring processes, but the independence can often be brought about by taking a transformation (such as the logarithms) of the measurements.

This error of measurement is not produced by the measuring instrument alone. The error may be caused by (1) the measuring device, (2) the technician using these devices, (3) the environmental conditions under which the measurements are made.

An illustration of the possible effect of environmental conditions in a production line setup is given in the following example.

A sample of 50 of a particular product was selected at random. See Figure I.

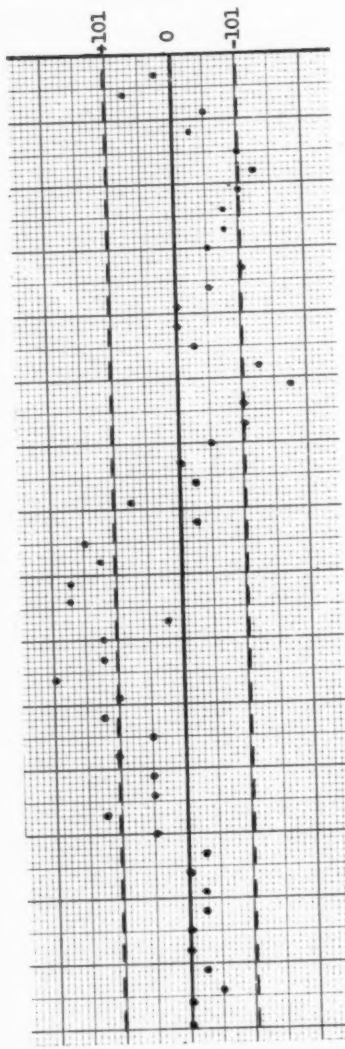
M_1 represents the measurements (in sequence of measurement) of a particular quality characteristic of each member of the sample. M_2 represents measurements on the same sample, with the same measuring equipment and the same technician, on a different day. D represents the algebraic difference between each pair of measurements. The adjacent control chart plots these differences. The $3\sigma_D$ limits are set by taking ranges of successive groups of two D's and estimating σ from $\bar{R}$. Even without limits, the cyclic pattern of points clearly indicates the presence of an assignable cause of variation. Since the samples were selected at random and since D is the difference of the two measurement errors alone, any such pattern can only be caused by the measuring process itself. Indeed, it was caused by fluctuating environmental conditions during measuring.

This method of estimating σ is much less affected by the cyclic pattern than a more easily computed estimate of σ described below in Figure II.

M_1	M_2	D ($M_1 - M_2$)
2325	2300	25
2150	2075	75
2550	2600	- 50
2375	2400	- 25
1925	2025	-100
1850	1975	-125
1225	1325	-100
2125	2200	- 75
1700	1775	- 75
2100	2150	- 50
2200	2300	-100
1750	1800	- 50
2075	2075	0
2200	2200	0
2300	2325	- 25
2175	2300	-125
1725	1900	-175
1575	1675	-100
2325	2325	0
2400	2450	- 50
1825	1825	0
2100	2125	- 25
1600	1525	75
1850	1875	- 25
2350	2200	150
2200	2075	125
1825	1650	175
2050	1875	175
2325	2300	25
1950	1825	125
2125	2000	125
1700	1500	200
2250	2150	100
1975	1850	125
2300	2250	50
1875	1775	100
1875	1825	50
2175	2125	50
1975	1850	125
2025	1975	50
1975	2000	- 25
1825	1825	0
1550	1575	- 25
2225	2250	- 25
2150	2150	0
1950	1950	0
2000	2025	- 25
1700	1750	- 50
2050	2050	0
1950	1950	0

$\bar{D}$ = 10, $\bar{R}$ = 37, $\sigma_D = \bar{R}/d_2$ = 33.8, $3\sigma_D$ = 101.4

Figure I



We cannot safely assume that the error of measurement is random. Not only may variation in environmental conditions affect measurements, but erratic behavior of either the instruments or of the technicians may also have a serious effect.

The significance of errors in measurement is greater in some production fields than in others. Where specifications are tight, where precise estimates of variability and quality of a product are required, where it is essential that the error of measurement be reduced, it is necessary to find a method for estimating u_ε and σ_ε.

In Figure II, a method of estimating σ_ε is illustrated. y_{A_1} and y_{A_2} are two sets of measurements on a sample of 36 made with a measuring process called A. y_{B_3} is a third set of measurements on the same sample with a different measuring process called B.

D represents the algebraic difference between two measurements on the same sample. R represents the absolute value of the same difference and is the range of two measurements. These differences between two measurements are actually the differences between the two errors of measurement since

$$D = y_1 - y_2 = (x + \varepsilon_1) - (x + \varepsilon_2) = \varepsilon_1 - \varepsilon_2.$$

These estimates of standard deviation based on the range are negligibly less efficient than estimates based on computations using the second moment. We do assume that the true mean of the D's is zero. In this example $\overline{D}_1 = 0$ and $\overline{D}_2 = 7.6$. Since $\sigma(D_2) \sim 100$, we are safe in this assumption.

If we are concerned with just one measuring process, two sets of measurements such as y_{A_1} and y_{A_2} on a relatively small sample treated in the above manner are sufficient for an estimate of u_ε and $\sigma(\varepsilon_A)$. It is assumed that the process of measurement is not destructive and does not affect the characteristic being measured. We could take many repeated measurements of the characteristic on a sample of one and compute σ_ε by conventional methods. This, however, is not truly representative of the measuring process under production conditions and may not characterize the variation which exists under the actual operating situations. Furthermore, we lose the opportunity to look for randomness of error as illustrated in Figure I.

Frequently, two measurement processes are available, one of which does not affect the measured characteristic of the sample, while the other is partially or completely destructive. A simple example would be the nondestructive measurement of thickness of plating by using the principle of magnetic fields as against destructive tests which require removal of plating with comparative measurements of thickness. A destructive test cannot be repeated on the same sample. If we have a destructive measuring process B, we can apply this measuring process after measuring process A has been applied twice to the sample and proceed as illustrated in Figure II.

In the procedure described, A and B may differ as measuring processes only to the extent of having a different technician do the measuring. The $\sigma(\varepsilon_A)$ and $\sigma(\varepsilon_B)$ then become the errors of the technicians. Or similarly, the same technician may use two different measuring instruments, so that $\sigma(\varepsilon_A)$ and $\sigma(\varepsilon_B)$ represent estimates of error due to instruments alone. By periodic repetitions of measurement by the same technician with two

Figure II

y_{A_1}	y_{A_2}	y_{B_3}	D_1 $(y_{A_1} - y_{A_2})$	D_2 $(y_{A_1} - y_{B_3})$
1575	1600	1650	- 25	- 75
2375	2375	2450	0	- 75
2150	2025	1925	125	225
1975	1900	1750	75	225
2025	2000	2100	25	- 75
2100	1950	2025	-150	75
1775	1750	1625	25	150
1675	1850	1675	-175	0
2425	2350	2325	75	100
1950	1975	2100	- 25	-150
2350	2350	2450	0	-100
1850	1875	1850	- 25	0
1675	1600	1600	75	75
2000	2000	2050	0	- 50
2250	2350	2350	-100	-100
1925	1875	1975	50	- 50
2575	2400	2500	175	75
1825	1825	1825	0	0
2050	1925	1925	125	125
1600	1650	1775	- 50	-175
2150	2100	2075	50	75
1800	1875	1850	- 75	- 50
2350	2400	2325	- 50	25
1550	1525	1625	25	- 75
1900	1875	1825	25	75
2075	2000	2025	75	50
2225	2175	2125	50	100
1925	1925	1775	0	150
1625	1675	1650	- 50	- 25
1775	1825	1900	- 50	-125
1350	1425	1400	- 75	- 50
1500	1475	1450	25	50
1800	1950	1825	-150	- 25
1650	1550	1650	100	0
1725	1825	1725	-100	0
1900	1900	2000	0	-100
$\sigma^2(y_{A_1})=83002$	$\sigma^2(y_{A_2})=70436$	$\sigma^2(y_{B_3})=79653$	$\bar{D}_1=0$ $\bar{R}_1=61.1$	$\bar{D}_2=7.6$ $\bar{R}_2=79.9$

(1) $\sigma(\varepsilon_A) = \bar{R}_1/d_2 = 61.1/1.128 = 54.2$

(2) $\sigma(D_2) = \sqrt{2}\bar{R}_1/d_2 = 79.9 \times \sqrt{2}/1.125 = 100.1$

(3) $\sigma^2(D_2) = \sigma^2(\varepsilon_A - \varepsilon_B) = \sigma^2(\varepsilon_A) + \sigma^2(\varepsilon_B) = 10020.01$

Squaring (1) $\sigma^2(\varepsilon_A) = 2937.64$

Subtracting $\sigma^2(\varepsilon_B) = 7082.37$

$\sigma(\varepsilon_B) = 84.2$

different instruments or by two different technicians using the same instrument, control charts plotting the differences of pairs of measurements provide estimates as well as means of control of the errors of measurement, just as control charts are applied to a production process.

Methods of estimating the error of measurement appear in the literature (1). Where only one measurement can be made with each of two measuring processes A and B, the following procedure is described:

$$\text{Since } y = x + \varepsilon$$

$$\sigma^2(y_A) = \sigma_x^2 + \sigma^2(\varepsilon_A)$$

$$\sigma^2(y_B) = \sigma_x^2 + \sigma^2(\varepsilon_B).$$

$$\text{Thus } \sigma^2(y_A) - \sigma^2(y_B) = \sigma^2(\varepsilon_A) - \sigma^2(\varepsilon_B).$$

$$\text{In addition } y_A - y_B = (x + \varepsilon_A) - (x + \varepsilon_B) = \varepsilon_A - \varepsilon_B$$

$$\text{so that } \sigma^2(y_A - y_B) = \sigma^2(\varepsilon_A - \varepsilon_B) = \sigma^2(\varepsilon_A) + \sigma^2(\varepsilon_B).$$

Knowing the sum and difference of two variances, it is possible to solve algebraically for the variance of each measuring process. Only one measurement on each member of the sample with each process is required.

Applying this to the data of Figure II, we assume only measurements y_{A_1} and y_{B_3} are available:

$$\sigma^2(\varepsilon_{A_1}) - \sigma^2(\varepsilon_{B_3}) = 83002 - 79653 = 3349$$

$$\sigma^2(\varepsilon_{A_1}) + \sigma^2(\varepsilon_{B_3}) = 10028.$$

$$\text{Adding: } 2\sigma^2(\varepsilon_{A_1}) = 13377$$

$$\sigma^2(\varepsilon_A) = 6688$$

$$\sigma(\varepsilon_A) = 85.$$

This procedure is theoretically sound but it must be noted that $\sigma^2(y)$ must be used. Since this variance is large compared to the error variances, the sampling error of the computed σ_y^2 is relatively large unless the sample size is very large. Hence, such estimation based on a small sample of 36 is not advisable.

Having estimates of $\sigma_{\varepsilon_A}^2$ and $\sigma_{\varepsilon_B}^2$ it is possible to estimate σ_x^2, by the relationship:

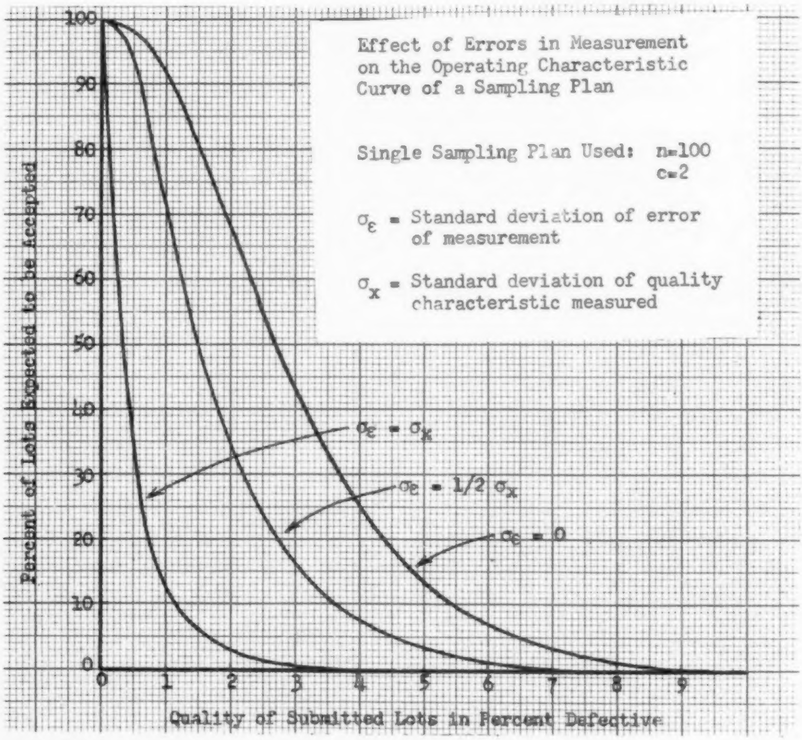
$$\sigma_x^2 = \sigma_y^2 - \sigma_\varepsilon^2.$$

Each of the three columns in Figure II gives one estimate so that the best estimate is an average of the three.

From column y_{A_1}, $\sigma_x^2 = 80064$; from column y_{A_2}, $\sigma_x^2 = 6779.8$; from column y_{B_3}, $\sigma_x^2 = 72571$. The average is 73478 so that the best estimate of $\sigma_x = 271$.

In conclusion, it may be of some interest to note the effect on acceptance sampling operations when a substantial error in measurement is present. We consider a situation in which a one-sided specification is applied to a measurable quality characteristic of a product and any member of a sample on the wrong side of this specification is considered a defective. Figure III shows the Operating Characteristic Curves of a Single Sampling Plan with a sample size of 100 and an acceptance number of 2 for cases of different relative values σ_ε. Obviously, for σ_ε greater than one half of σ_x, the sampling plan becomes much more stringent than for the case of $\sigma_\varepsilon = 0$. The selection of a particular sampling plan is usually determined by the characteristics of its Operating Characteristic Curve. Therefore, the choice of a sampling plan should be influenced by the magnitude of the error of measurement.

Figure III



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(1) Grubbs, F. E., "On Estimating Precision of Measuring Instruments and Product Variability", Journal of the American Statistical Association, June 1948, Vol. 43, pp. 243-264.

EFFECT OF MEASUREMENT ERROR ON CHEMICAL PROCESS CONTROL

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A statistical approach to problems arising from a particular type of scientific or industrial endeavor will inevitably lead to the use of statistical techniques which are best adapted to the nature of the problems encountered and the experimental data available. Historically, most broad classes of statistical techniques have been developed in close association with some field of application; for example, the development of correlation techniques in connection with the genetical and, more recently, psychological study of human populations, the development of the principles of experimental design in connection with agricultural research, and the development of statistical quality control in connection with the problems of mass production of manufactured items. Thus as statistical methods are applied to new fields, it becomes necessary to modify existing methods, or develop new methods, so that the peculiar needs of these new fields will best be served. Of course, this is true not only for general areas of application but for every new problem which is to be attacked by statistical methods; however, problems arising in a particular science or industry frequently have common characteristics which dictate the statistical approach to be used.

The rapid growth in recent years of the use of statistical methods in both chemical research and production has made necessary an examination of the applicability of existing statistical methods in this field, and has already led to new developments directly related to chemical problems. Some things which have been and are being considered are experimental designs more closely related to the particular needs in chemical experimentation, simple estimation techniques for use with the very small numbers of repeated measurements available in most chemical work, and modifications of the assumptions underlying the analysis of variance necessary to increase the applicability of this powerful tool to chemical data. The question of the applicability of statistical quality control techniques to chemical production processes has also arisen, and it is with one particular aspect of this problem that this paper is concerned.

The aim of chemical process control is identical with that of the control of any mechanical process. Both intermediate and final product must meet certain specifications, usually stated in terms of some measurable quality characteristic. There is little basic difference in the attitude of management toward scrap losses and waste losses, or toward final product rejects and final product purity. However, there are some characteristics of chemical processing which require special attention when control procedures are to be established. Two of the most important of these are:

(1) In chemical processing we are usually dealing with a more or less continuous flow of a product material, rather than with specific manufactured items. At best we may be dealing with a batch process, in which a given quantity of material is processed as a distinct unit, roughly corresponding to a lot of manufactured items; at worst (from the point of view of control) we may actually have a continuous production flow with the material divided into discrete units only as bottles, carboys, drums, tankcars, etc. of raw materials received and final product produced. Thus in place of variation of a quality characteristic from item to item we are faced with a continuous process variation measurable only in terms of

the average quality of some arbitrary unit of quantity.

(2) Even supposing that we do have some natural unit on which to base our measurement of product variation, it is difficult to establish what this variation should be--i.e., to what it should be compared for control purposes. This is due to the fact that in determining the average quality level of a batch of a chemical we have to face not only the sampling variation due to lack of homogeneity within the batch, which is somewhat analogous to the variation within a lot of manufactured items, but also the variation in the analytical determination of the quality of the sample.

It is the relative magnitude of this measurement error which constitutes one of the major differences between chemical process control and the control of a mechanical process. In the latter case it is generally possible to measure the quality characteristics of an individual item, such as weight, length, inside diameter, clearance, breaking strength, hardness, etc., with sufficient accuracy so that the measurement error can be neglected, and the variation in the results assumed to be due completely to process variation. However, in chemical production the best analytical determinations of the quality of a batch of raw material of product, or a sample from this batch, frequently vary as much as or more than the average quality of the batches themselves.

The data shown in Table I are typical of these considerations. These are the results of a special study of the metal content of two types of metallic oxide, produced by essentially the same process from two types of raw material. The lots of each type represent consecutive production, and the sampling and analytical techniques used were identical. Two distinct samples were taken from each lot by a thief technique, and after some additional preparation submitted to the laboratory, where two different chemists did independent duplicate determinations of the metal content in percent by weight. The pairs of chemists assigned were not necessarily the same, nor necessarily distinct, depending on chance assignment in the laboratory. Estimates of the variance components obtained from these data are given in Table II.

TABLE II

Estimated Variance Components

Source of Variation	Type 1	Type 2
Lots	0.0620	1.3673
Samples	0.0683	0.0252
Chemists	0.0201	0.0407
Determinations	0.0423	0.0492

In this case the primary interest was in the variation between lots, as an indication of the adequacy and consistency of the processing, so that all of the last three sources of variation, including sampling, can be considered as measurement error, as opposed to processing error. In controlling a continuous flow, variations from sample to sample are frequently the only indication of product variation, and hence sampling

TABLE I

Results of a Special Study on Consecutive Lots of Metallic Oxide

	Sample A				Sample B			
	Chemist 1		Chemist 2		Chemist 1		Chemist 2	
Lot	1	2	3	4	1	2	3	4
Type 1								
1	84.1	84.0	84.3	84.3	84.1	84.0	84.1	84.1
2	84.1	84.0	84.0	83.9	84.2	84.2	83.7	84.6
3	83.5	83.5	83.4	83.6	83.4	83.3	84.0	83.5
4	84.2	84.2	84.2	84.3	84.1	83.7	84.1	84.6
5	83.7	83.8	83.3	83.3	83.2	83.1	83.1	83.2
6	84.0	84.2	83.8	84.2	84.1	84.3	84.2	84.1
7	84.0	83.8	83.8	84.0	83.6	83.8	83.9	83.8
8	83.8	83.9	84.0	83.9	84.0	84.0	84.2	84.0
9	84.2	84.5	84.3	84.1	83.8	83.7	83.8	83.8
10	83.6	84.0	84.0	83.7	83.9	84.1	84.2	83.7
11	84.6	84.6	84.0	83.4	84.4	84.5	83.9	84.1
12	83.3	82.9	83.2	83.9	82.9	83.7	83.3	83.4
13	84.5	84.5	84.0	84.2	83.7	84.0	84.0	83.9
14	83.8	83.8	83.5	83.6	84.3	84.1	83.8	83.8
15	84.2	84.1	83.8	83.8	83.8	83.8	83.9	83.9
16	84.2	83.4	83.7	84.1	84.4	84.5	84.0	84.0
17	83.3	83.4	83.9	84.0	82.2	82.3	82.4	82.7
18	83.6	83.7	83.6	83.5	84.1	84.0	84.4	84.2
Type 2								
1	83.4	83.4	83.6	83.5	83.7	83.5	83.1	83.4
2	84.2	84.1	84.3	84.2	84.2	84.2	84.3	84.2
3	83.5	83.5	84.2	84.5	83.4	83.7	83.9	84.0
4	83.4	83.3	83.5	83.1	84.2	84.2	83.3	83.1
5	83.2	82.8	83.1	82.7	83.0	83.0	83.2	82.7
6	80.2	80.7	80.8	80.7	80.3	80.4	80.2	79.0
7	80.9	80.6	80.3	80.6	81.0	81.1	80.7	81.0
8	83.3	83.5	83.5	83.4	83.9	83.7	83.7	83.7
9	82.9	82.6	82.8	82.9	83.1	83.1	82.9	82.7
10	83.8	83.8	83.9	83.8	83.4	83.6	84.0	83.8
11	83.8	83.4	83.6	83.8	83.8	83.6	83.9	84.0
12	83.2	82.5	83.0	83.5	84.3	83.5	83.8	83.8
13	83.4	83.4	83.3	83.3	83.5	83.5	83.2	83.3

error would be included with process variation. Note that for Type 1 lots the estimated measurement error is actually greater than the variation between lots. However, for Type 2 material the variation between lots is appreciably greater than the variation in measurement, although this is primarily due to the large discrepancies in lots 6 and 7. The overall measurement error is comparable for the two types of material, as might be expected; although the difference in sampling variation approaches significance, no apparent reason for this could be found, and the difference is in the opposite direction from that to be expected from the nature of the material processed.

One of the immediate consequences of the presence of an appreciable measurement error such as that exemplified above is that adequate control of the process is possible only if we have adequate control of the measurements. Since most chemical process control measurements are based on chemical analyses of one type or another, this means that the statistical control of a chemical process must inevitably be preceded by the establishment of statistical control over the analytical facilities used, whether in the form of analytical instruments used by production personnel or analytical laboratories whose primary function is the analysis of control samples. Such control can be established by the analysis of standard samples, which enables an evaluation of both the variation in the determination and the presence or absence of an appreciable bias, and/or by repeated determinations of the content of a particular batch. How much control of either or both of these types is possible will be dictated by the economics of the particular situation considered. The use of standard samples enables the determination of systematic bias; however, in most other respects it is inferior to the use of repeated measurements as a means of controlling measurement errors. It should be pointed out that although it is rarely possible to routinely analyze each lot in the systematic manner used in the above special study, the repeated analyses used for measurement control (generally two, and occasionally three or four), should include as many of the sources of measurement error as is economically feasible. Consider, for example, the validity of concluding that there had been a real variation in the processing of lot 6, Type 2, based on the first two results as opposed to the validity of the same conclusion based on the second and next to last results.

Now let us suppose that we have established satisfactory control of gross measurement errors. There will still remain a random measurement variation which may be of the order of magnitude of the variation in the product. The general effect of the presence of such an error is to lower our power to detect abnormal process variations--i.e., a given change in the process average will have less chance of occasioning a point out of control. To illustrate this effect, let us consider a process for which the normal batch to batch variation is σ_p^2, and the normal measurement variation (including any reduction due to replicate measurements) is σ_m^2. Then the overall variation in an individual result is given by $\sigma^2 = \sigma_p^2 + \sigma_m^2$, and control limits for an individual result would be of the form $\mu \pm k_1\sigma$, depending on the type of limits used. We can now easily compute the probability that a shift in the process average of $k_2\sigma_p$ will produce a point out of control. Plots of this probability versus k_2 are shown in Figure 1 for $k_1 = 2,3$ and $r = 0,1,2$, where $r = \sigma_m/\sigma_p$ is the ratio of the measurement standard deviation to the process standard deviation. $r = 0$ corresponds to the usual situation where any change in the process average is compared to the process standard deviation. For example, using 3σ control limits the probability that a

change in process average of three times the process standard deviation will produce a point out of control is about 0.50 for $r = 0$ (no measurement error), while for $r = 1$ (measurement variation and process variation the same) this probability is reduced to about 0.19. Note that the greatest decrease in power occurs with respect to process variations which are of the magnitude of $k_1\sigma$; large changes in process average will almost certainly be detected in any event.

There is no hard or fast rule as to when the above situation becomes untenable. If, in spite of the fact that the usual process variation is of the order of magnitude of the measurement error, changes in process average of engineering or chemical significance are quite large, the control available may be perfectly adequate. If changes of the order of, say, three to six times the process standard deviation are of engineering significance, then it may be necessary to reduce the measurement error. This may be done by making repeated measurements on a batch; for example, the estimated variation of the measurements for Type 1 material given in Table II could be made less than the estimated process variance simply by taking two samples and assigning them to different chemists for duplicate determinations of the metal content. However, the use of repeated measurements for this purpose, as opposed to their use to control gross measurement errors, is frequently economically unsound. A better, although sometimes difficult, solution is to develop sampling and analytical procedures which have a sufficiently small random error. If neither of these are feasible we must simply resign ourselves to a control which is less sensitive to changes in process average than we would prefer.

A final consideration, which may give us additional insight into the adequacy of a method of measurement for the control of a chemical process is that we are frequently interested as much, if not more, in the content of a particular batch as in the variation in content from batch to batch, or changes in the process average. If the measurement errors and the process variations are both reasonably random, we can ask at what point an individual measurement on a batch ceases to be a better estimate of the content of the batch than the process average--i.e., at what point do we begin to introduce more error by measuring than by ignoring the processing variation. The answer, of course, is simple: If the measurement variance is less than the process variance, it pays to measure each individual batch, but if the process variance is less than the measurement variance, we are better off to use a well-established process average. Of course, this conclusion is predicated on a controlled process and controlled measurements, which means that we cannot stop making measurements; this applies only to the decision as to what answer we report on a particular batch. However, it does establish $r = 1$ as somewhat of a dividing line between adequate and inadequate methods of measurement in the absence of other considerations. Actually, on the basis of the data in Table I, and some further indications of the stability of the process for Type 1 material, it was decided to report the process average for each batch of material of this type, and to make analytical determinations only on a composite of five samples from individual batches for control purposes. This procedure has been used successfully for some time.

The presence of measurement error to a greater or less extent is characteristic of all chemical processing problems. The above discussion has indicated some of the ways in which we must modify our thinking with

respect to the control of the chemical process and some of the considerations which are important in attempting such control. While this is by no means all inclusive of the problems which arise because of the presence of measurement error, it is hoped that those who have to deal with the control of a chemical process can obtain some ideas which will be helpful in their particular problems.

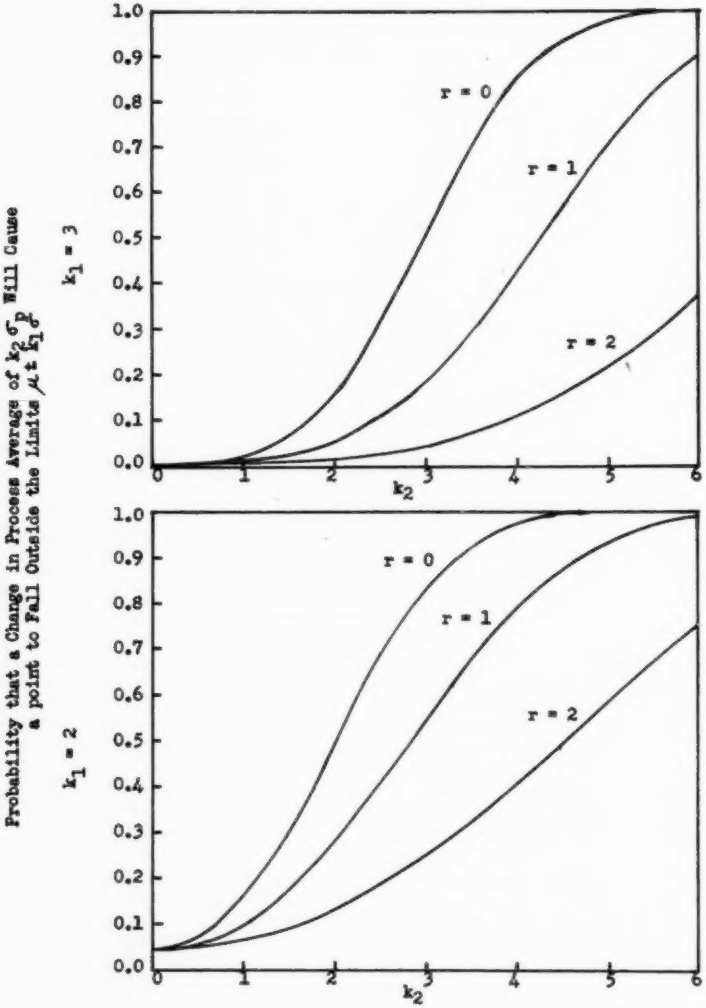

FIGURE 1. Effect of Measurement Error on the Power of the Control Limits.

THE TECHNIQUE OF PREVENTING DEFECTS

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Let us start with the flat statement that "Quality Control is the science of preventing the manufacture of defective product". There are many who might quarrel with that definition of quality control as being too limited in scope. In the sense of a definition, they are probably right. On the other hand, as a capsule statement of the importance with which the preventive point of view must be reflected in any serious attempt at modern quality control, it would find many adherents. The most noted exponent of this idea has been Dr. J. M. Juran, who has made a careful analysis of the reasons why some quality control programs succeed and others fail. He says: "There must be a recognition of the fact that the basic objective is prevention of defects and that all else is seconday." (1) Whether we wish to define quality control as defect prevention or not, it is true that, aside from the employment of statistical methods, the preventive philosophy is the one single new and significant concept that distinguishes modern quality control from its predecessors in the field of industrial cost control.

Juran has woven the theme of defect prevention into much of his writing and no discussion of the techniques for preventing defects can start without a brief review of some of his brilliant analyses and arguments along these lines. Juran (2) sees the quality function in industry as comprising three main elements: (1) Acceptance, (2) Prevention and (3) Assurance.

Acceptance is the daily inspection job of accepting and rejecting specific items of product. It embraces both 100% inspection and sampling inspection, whether performed on incoming raw materials, parts in process, sub-assemblies or on finished articles ready for shipment. It includes keeping records and charts and doing day-to-day trouble shooting. Prevention is the "quality control engineering" job, utilizing all of the modern statistical and managerial techniques, aimed at solving quality problems and devising means to prevent their future recurrence. Among the techniques used are: process capability analysis, control chart analysis, design of experiments, design of sampling plans, and others. Assurance is the job of determining the existing quality of product and policing the system for maintaining quality. It involves the techniques of check inspection, quality audit, analysis of consumer complaints, determination of market quality, and others.

This breakdown by Juran is primarily designed to show the separate nature of the three quality control jobs and to suggest a form of organization through which the complete quality function may be fully covered. It does not infer that the prevention concept is limited to one specialized regiment of the quality control "brigade"; skill in applying prevention techniques may be concentrated in a small part of the organization, but the philosophy of prevention must pervade the entire quality control activity. Reflect, for example, on the singular ineffectiveness of a sampling inspection acceptance plan in which no provision is included for notifying the producing operator of the rejection of a lot. Or consider the spinelessness and futility of a quality assurance plan which management refuses to take seriously enough to spur an investigation of the reasons for extraordinary deviations. Neither of these acceptance or assurance jobs has a "built-in" prevention device. As every quality control neophyte has been told and every practitioner knows, no technique can succeed or survive

unless it is linked securely to the preventive idea. The statistical techniques are no exceptions. They contribute to all three elements of the quality function, but they can do little if management is unwilling to accept the preventive philosophy. (3)

The idea of prevention is obviously not a new one. Indeed, there is scarcely a field of human endeavor where it has not taken hold, once the knowledge and tools for prevention become available. Fire prevention, crime prevention, preventive medicine, preventive maintenance and accident prevention are a few of the fields in which the idea has successfully germinated. Each of these is actually the outgrowth of an activity originally established -- and still existent -- to cope with the immediate effects of the "disease, death or disaster", i.e. fighting fires, detecting crime, healing the sick, repairing the wreck, etc. But the human mind is not content with putting out fires; from the accumulated experience of fire-fighting, it seeks out the most frequent causes of fires and, once these are known, it devises techniques and programs to battle these causes. The defect prevention idea was born of the same circumstances. It came from the observation of repeating patterns in the causes for defectives and the powerful desire to battle these causes. It is simply the concept that it is far better and cheaper to prevent defects from happening than to suffer the toll they take in dollars and morale.

Ten years ago, this was still largely an idea. Today, however, there is little doubt that this idea, together with the techniques for achieving it, is one of the most powerful means for reducing scrap, rework, complaint and inspection bills in industry. Many have pointed to the lush savings they have been able to secure. Juran's widespread experience in a number of companies leads him to the statement that a good quality control program can usually succeed in reducing the "cost of defects" -- which includes those items listed above -- by 50%. (4)

Techniques for Defect Prevention

What, then, are the means for achieving this desirable situation? To begin with, we must divide them into two broad classes:

(a) Those which are employed when the know-how for prevention is available, but is not being used.
(b) Those which are employed when the know-how for prevention is not available and so must first be obtained.

When a machine or process is producing parts that normally meet the specification requirements and when the operators of these machines or processes fully understand the operation and adjustment of the process, then the know-how is available and there is no reason why defectives should be made. But often they are made, because the operator is careless, or is on a poorly-conceived incentive system, or because the foreman insists on running the machine too fast, or because the material specification is changed without adequate investigation or because .....

When this situation is rampant throughout the plant, then it is obvious that use is not being made of existing know-how. Prevention of defects is then a human relations problem and must be attained through the careful use of the many ways of influencing human behavior. Some of these are: development of better working conditions, better supervision, better disciplinary methods, better incentives for quality, educational campaigns based on posters, slogans, contests, etc. All of these seek, through indocrination with "quality-mindedness", to achieve that kind of a working environment in

which the preventive philosophy can be successfully nurtured.

However, when the know-how for preventing defectives is simply not available, then no amount of exhortation or incentive -- however cleverly contrived -- can bring about the desired quality improvement. In the complex fabric of modern mass production -- with the quality responsibility divided among many hands and minds -- it is fairly common to find that the know-how does not exist. Ultimate failure of the product to meet specifications may arise from many sources and, until new facts are collected and analyzed, it is impossible to know how to prevent defectives. Such situations vary in complexity all the way from simple machine operations, where a few hours of fact-finding will suffice, to the more complicated processes involving several operations that may require several months of experimenting and fact-gathering before a control system can be achieved.

The development of this necessary know-how involves a three-fold mode of attack: (5)

1. Reliance on the scientific method of collecting facts instead of opinions.
2. Analysis of these facts by specialists trained and qualified in the new techniques.
3. Coordination of results to provide the necessary action or modification of existing practicies.

If such a program of defect prevention is carried through, it will ultimately affect every function in the enterprise. For it becomes crystal clear that the defect prevention attitude must start with the design of the product, carry through the planning, manufacturing, inspection and testing stages and not end until the product is in the hands of a satisfied customer.

Let us examine in more detail how the prevention function operates in developing and analyzing new facts to improve existing know-how.

Roots of Defect Prevention Problems

The basic tenet of the defect prevention "faith" is the belief that defects have causes, they do not "just happen". It then follows axiomatically that the cause of a particular defect can be discovered. Once discovered, it is held that human ingenuity will usually be able to devise a method of eradicating or minimizing the cause. In brief, these causes or "roots" may be multitudinous, but they are not mysterious.

A convenient and alliterate classification of the roots of defect prevention problems is given by Feigenbaum (6), who uses the headings: Men, Materials, Methods, Machines, Management. Utilizing this classification, let us list some of the typical situations in the industrial environment that lead to the manufacture of defects.

Men

1. The engineers who create an impossible design or impossible tolerances.
2. The planning men who provide inadequate equipment.
3. The purchasing agent who selects an unqualified vendor or who fails to acquaint him with the quality requirements that do not appear on the blueprint.
4. The time-study man who sets the price too tight, or who fails to allow for operator-inspection when it is feasible.

5. The operator who does not have the necessary skill or is not conscientious, or is not properly trained.
6. The inspector who is ditto.

Materials

1. The purchased material that is never inspected until it arrives at the assembly department and will not fit.
2. The purchased material that is out of specification, but has to be accepted anyway because "we can't afford the delay of rejecting it".
3. The purchased material that is made wrong, but could just as well have been made right if only the vendor had known what was really wanted.

Methods

1. The measuring or testing instrument that is not sensitive enough to reveal the location of the process within the tolerances.
2. The inspection procedure that waits until all the parts are made before deciding whether they are good or bad.
3. The gaging system that measures two unimportant dimensions to control a functionally important dimension instead of measuring that dimension itself.
4. The method of specification that establishes tight tolerances to compensate for shop laxity; they are not really expected to be met and so nobody pays any attention to them.
5. The worn jigs and fixtures, the inaccurate tools, the obsolete gages that continue to be used because "that's all there is, there ain't no more".
6. The heat-treating cycle that was specified in a hurry one day five years ago and never has succeeded in producing the right hardness.

Machines

1. The machine that does not have the capability to meet the tolerances.
2. The makeshift machine that was designed for another use, but was adopted temporarily -- two years ago.
3. The machine with the worn ways or the wobbly spindle or the egg-shaped shift that should have been fixed, but the accounting department said it wouldn't increase production enough to pay for itself in six months.

Management

1. The management policy that pays piece work rates for total production instead of good work only.
2. The superintendant who berates his foremen soundly for failing to meet the production quota but never even glances at their quality record.
3. The foreman who mouths pretty phrases about getting the right quality, but howls like a stuck pig when some inspector takes him seriously and shuts down a machine to help him get it.
4. The boss who spends all his energies fighting inspection instead of fighting the defects and eliminating the need for inspection.
5. The executive who bemoans the passing of "pride of workmanship" as a lost art instead of searching out means for restoring it.

The list could be extended for many more pages, but the idea is clear -- these are the "stuff" defectives are made of. It should also be evident that the specific cause of a particular defect will never be obvious until the fact-finding and analysis has been carried out.

Finding the Right Preventive Device

After the roots of the problem have been located, much consideration must be given to the question of finding the right type of preventive device. Excluding the situations having purely mechanical solutions, it can be said that there is a right preventive technique for the particular time and place, but that that same technique may not be right for the same problem at a different time or in a different plant, or even in a different department of the same plant. There is, in other words, a kind of fourth dimension about the selection of the preventive technique to be used. Not only must it solve the particular defect problem to which it is applied, but it must be physiologically adapted to the environment and the personnel who must use it at that particular time.

A good example of the temporal propriety of the preventive technique is afforded by a review of the history of one particular problem through four separate phases over a space of 4 years.

First Phase

In the assembly department of a certain high volume operation, a study was made of the frequency of occurence of certain types of defects. It was discovered that the major cause of assembly rejects came from defective soldering in one of the sub-assemblies. So costly was the process of tearing down the assembly, stripping the defective parts, resoldering and replating them that it was decided to institute a 100% inspection of soldered parts prior to plating and assembly. For this time and place, this was an appropriate preventive technique. It took the problem out of the assembly department -- where little could be learned of cause and effect -- and put the burden of the defectives back into the department responsible; it could not help but stimulate interest in the problem if the defectives were sorted out "on the spot" and exhibited to all those directly concerned with the soldering.

Second Phase

As expected, this scheme successfully prevented assembly rejects, and the defect prevention problem was moved back to the soldering department. When the results of the 100% inspection were accumulated, it became evident that 15-20% of the sub-assemblies did not meet the soldering standards. To study this situation, arrangements were made to identify the work of each of the 12 soldering machine operators through the 100% inspection. Analysis of the data revealed the interesting fact that not all of the operators were equally responsible for the defectiveness. The work of some operators was distinctly superior to that of others. This led to the substitution of sampling inspection at the machine in place of 100% inspection. The trick was to move the defect detection device one step nearer to the source of the defects and provide much stronger pressure on each operator to "make 'em right in the first place".

Third Phase

The result of this change was startingly dramatic. Within a few weeks, the defectiveness dropped to about 2%. Each operator could now see the disposition of her own work and knew that a record was kept of her individual performance. She began to inspect her own work and make the necessary time and voltage adjustments to the soldering machine (actually an adapted welding transformer) whenever she was not satisfied with the quality. This preventive technique was right because it stimulated the use of existing

know-how and boosted "quality-mindedness" at a time when it was vitally needed. Most important of all, it capitalized on existing know-how.

As time went on, however, new diseases appeared. On certain days, almost all the operators seemed unable to control the machines satisfactorily, whereupon the defect rate would advance to 4-5%. At other times, certain individual machines went sour so that even the better operators could not run them. Moreover, it was noted that operators did not really understand how to make precise adjustments of the voltage; they frequently overadjusted and had to back off after running into trouble. It was becoming clear that the limit of existing know-how had been reached and that further prevention must come from the development of new know-how. The prescription was an intensive study of the innards of the machines.

Fourth Phase

The project is now in this phase. Already much has been done to develop better understanding of the process. Currents have been measured with ammeters, voltages with voltmeters, cycle times with electronic timers, electrode spacings have been gaged, uniformity of solder pre-forms has been scrutinized. Experiments with all of these variables included have been conducted to determine their influence on the quality of soldered joints. Results have not been so startling, since it must be remembered that the disease was one of sporadic flair-ups and their absence is harder to demonstrate than their presence. But certain chronic defects have already been virtually eliminated and what used to be considered "excellent" performance is now considered only "fair".

The objective in this phase is to reach the ultimate in defect prevention -- the development of a set of standard operating conditions for the machines and measuring devices for certifying that the machines are operating at these conditions before they are allowed to make parts for production. Call this preventive maintenance if you like; it is part of defect prevention. It will certainly eliminate much of what used to be classified as operator skill: what little skill factor remains will be the only residual cause for defects. The acceptance sampling plan at the machines will remain in force to keep tabs on that while it is too early to know the results, it will be surprising if a level of less than 0.5% defective is not attained.

Statistical Quality Control Tools as Preventers

The use of statistical quality control techniques, especially control charts, to diagnose and correct existing defect problems has been widely treated and is well understood. The preventive functions of these techniques have also been pointed out, but students of quality control do not always understand that the primary function of every statistical toolmust be its defect prevention function. It may be pertinent to explore this viewpoint briefly, considering acceptance sampling, process capability analysis and control charts as the statistical tools of major importance.

Acceptance Sampling

Sampling plans are usually considered as having the primary purpose of protecting the consumer against accepting poor quality product. But the more use one makes of acceptance sampling, the clearer it becomes that the only real consumer protection comes from having the product made right in the first place. After all of our sage deliberations on probability and OC curves, we are forced to admit that the quality which will be accepted

by a sampling plan tends to be pretty nearly equal to the quality that is submitted. Only in the event that a large amount of sorting is done can the claim of improved quality be substantiated and then it is doubtful whether a sampling plan should have been used in the first place. After all, 100% sorting is hardly sampling inspection.

The protection afforded by a sampling plan, therefore, does not come from its acceptance but rather from its rejection of lots and from the information it provides for creating awareness of the process behavior. Recognition of these facts leads to three basic rules for utilizing the preventive function of sampling plans:

(1) Locate the sampling as close as possible to the production source so that a minimum amount of time is lost between the fact of making defectives and its discovery.

(2) See that the information derived from the sampling inspection is passed on in proper form to the "submitter" and see that it is used to locate troubles and prevent future recurrences.

(3) Refuse to employ sampling unless the number of rejected lots will normally be few enough to act as a disciplinary measure to instigate action toward avoiding future rejections.

These principles have long been used in many quality control installations, particularly when the "submitter" and the "sampler" are two departments of the same company. There is, however, increasing evidence that the same thinking is penetrating the consumer-vendor relationship and will ultimately prevail in this field. Inspired by the Hunter Spring Company, several companies now perform inspection close to the source of production and furnish inspection records to their customers. The increasingly popular Hamilton-Standard-Lot-Plot method of acceptance inspection has a built-in provision for furnishing copies of inspection data to the vendor. The U.S. Air Force Procurement agency is developing its policy of reducing inspection of product to a minimum and concentrating instead on auditing the vendor's means for controlling quality and preventing defects.

Process Capability Analysis

The analysis of process capability, through the use of the frequency distribution, the $\overline{X}$ and R chart, the simple X chart, or the Multi-Vari chart, (7) is a well-known and well-used technique for trouble-shooting. It can be a valuable tool in the defect prevention program in two ways:

(1) The tackling of specific troublesome factory problems inevitably sheds more light on the causes for defectives and hence automatically results in improvement for that particular product. (8).
(2) The cataloguing and dissemination of capability data can give all plant personnel a new insight into many of their day-to-day problems and actually prevent many defect problems from ever arising. (9) In brief, the process capability information can be used to help all of the people who contribute to final product quality to do a better job. It is self-evident that fewer defects are produced under such circumstances.

Control Charts

It would be superfluous to dwell on the prevention benefits attainable through the use of control charts at the operating level. The conciseness

and definiteness with which the chart tells an operator or set-up man to adjust at the first sign of a trend toward making defectives, or the laboratory technician when to add chemicals to the bath, or the foreman when to investigate and when to sit tight -- all these and many other examples have been cited in the literature. It should be emphasized, however, that these defect prevention benefits will not generally be obtained unless it is first assured that the user of the chart actually knows the specific remedies for correcting the abnormalitites which the chart may reveal.

Some Case Studies in Prevention

On the following pages will be found six simple examples of the prevention philosophy at work in a variety of industries under a diversity of circumstances. Each story is necessarily brief, but it tells a poignant tale of recognition of the value of the preventive point of view. The author is indebted to his students at Northeastern University for the use of these studies; each represents the semester project of one of them. All company names are fictitious, but instances are real.

LAUNDERING OF SHIRTS

Lot Size - 1,000
Sample Size - 100

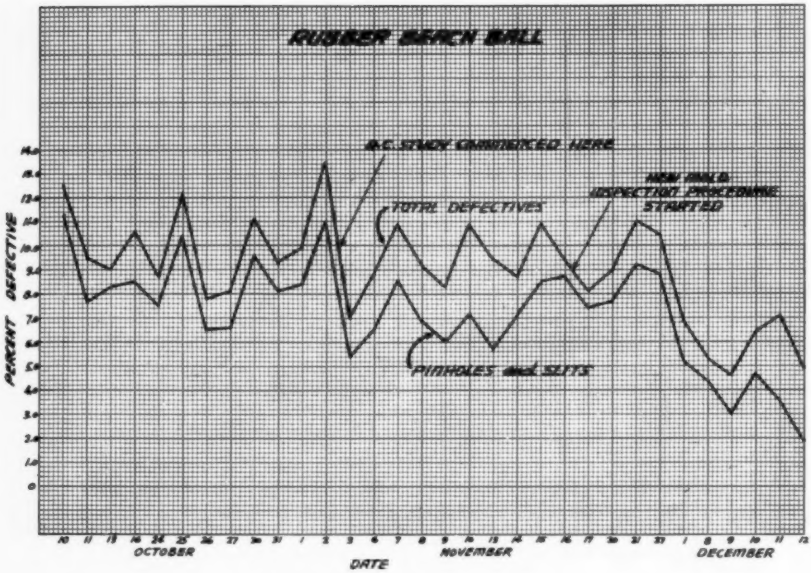
Day	Time	Wash	Starch	Iron	Pack	Misc.	TOTAL REJECTS
		CAUSES FOR REJECTION					
1	1:00 P.M.		/	卌		/	7
2	2:30 P.M.	//	/	//	/		6
3	11:45 A.M.	卌	//	卌			12
4	11:45 A.M.		/	//		/	4
5	3:00 P.M.						0
6	1:05 P.M.			/			1
7	10:00 A.M.	/		//		卌	8
8	1:00 P.M.	//	/		///		6
9	4:00 P.M.	///		卌			8
10	2:00 P.M.		/	//			3
11	1:00 P.M.						0
12	11:00 A.M.	/	/	/	/	/	5
13	11:45 A.M.			////			4
14	10:30 A.M.	/	/	卌		/	8
15	3:45 P.M.					卌	5
16	3:00 P.M.			////	/	//	7
17	10:00 A.M.	/	//	//		/	6
18	2:00 P.M.	//	/	///		/	7
19	1:30 P.M.		//	////			6
20	2:00 P.M.			/			1
	TOTALS	18	14	48	6	18	104

$$\bar{p} = \frac{104}{20 \times 100} = 5.2\%$$

PREVENT DEFECTS IN A LAUNDRY?

Fastidious male customers were complaining about stains, starch streaks and crumpled fronts in the shirts they received from the Home Laundry Co. The Laundry sales department investigated with a simple fact-finding device: every day for 20 days, a salesman made an unannounced visit to the "accumulation bins", last stop before boxing and delivery, scooped up 100 shirts and submitted them to a jury of salesmen for inspection. Shown above is the tally sheet with defects sorted by descriptions. "Ironing" stood out like a sore thumb. A campaign of operator-education among the ironers, coupled with clarification of quality standards and introduction of inspection by the ironer quickly brought the 5% level shown above to 1% within two weeks. Home Laundry Co. learned how to cut its complaint bill.

(Thanks to C.T.Capasso)



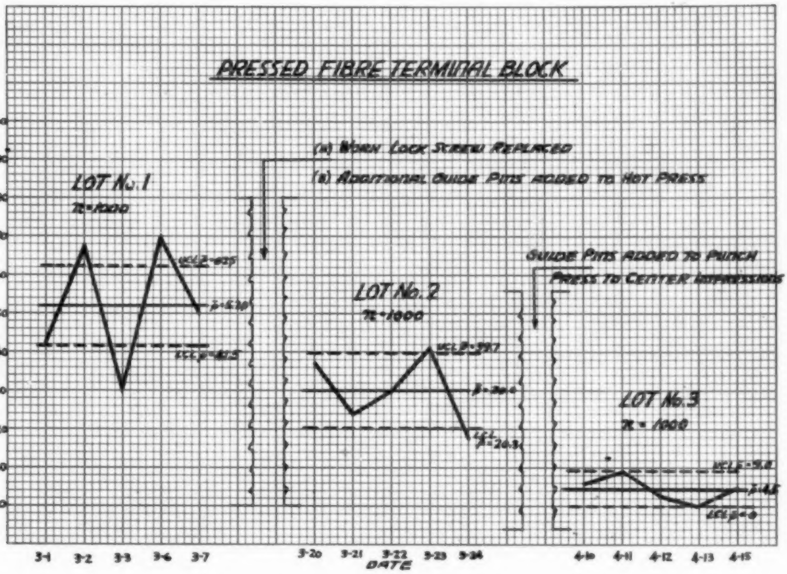
WHEN BEACH BALLS DON'T BOUNCE - POUNCE!

If you were making rubber beach balls and had 10% of them ending up in the scrap pile, you wouldn't be any happier than was the management of the Bounce Ball Co. But when you learned that 8.5% of the 10% were "pinholes and slits", you would make up your mind to apply the preventive philosophy; especially if you knew that cracked or dirty molds were the prime cause of these tiny defects. You probably would, as they did:

1-- Identify each production mold, inspect it weekly, yank it for cleaning when it needs it.
2-- Develop a new film coating material to apply after cleaning
3-- Use X-Ray inspection of all new molds to look for cracks.
4-- Develop a fixture to let you inspect the balls before vulcanizing the stem so you could move your inspection that much closer to the source of defectives.

You would have been mighty pleased, too, to see the pinholes begin to wane in December, as the graph shows. Your next step is to move the inspection right back to the molding operation to catch the defects even sooner.

(Thanks to J.P.Cahalane)



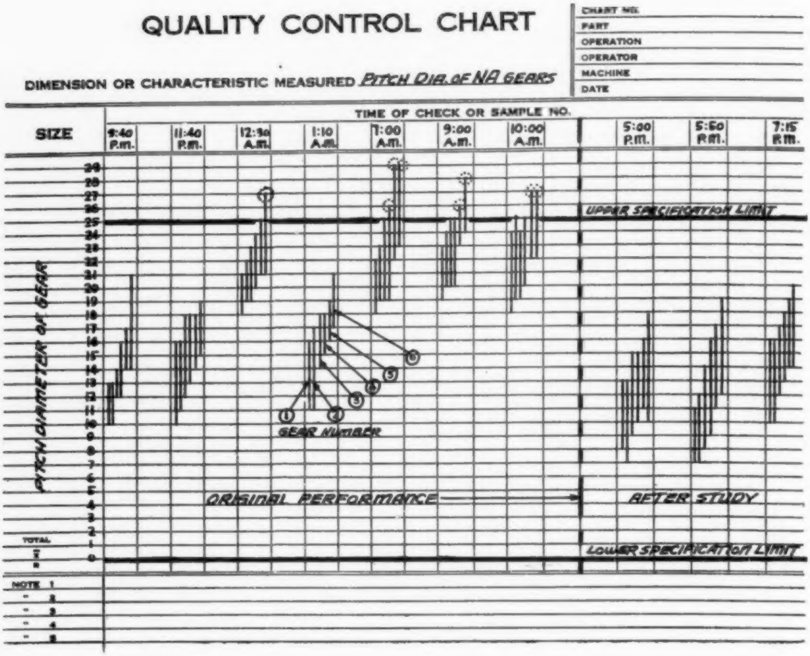
BUT WE'RE A JOB SHOP; OUR PROBLEM IS DIFFERENT!

That's what the Penult Pressed Fibre Co. thought until they really studied the terminal block job. It was ridiculous to have so much trouble with such a simple part -- that rectangular fibre strip with the square hot-pressed impression and the three punched holes. And yet, every time the order came through, it was a sure signal of trouble and Penult's customer got madder and madder every time he shipped the whole lot back to do over.

This time, they didn't run the whole lot of 3,000 through; instead, they took 1,000 and watched them carefully from the cutting press to the hot press to the punch press, inspecting the whole lot and making notes at each step. Armed with these facts, it was easy to prove that the 52% defective happened right at the cutting operation because a lockscrew kept slipping. They fixed the screw, and added a "built-in" defect preventer -- extra guide pins at the second operation which would refuse to accept oversize pieces.

The second lot fared better; it was only 30% defective. Luckily, they had kept watch and again were able to point to the culprit -- a missing guide pin in the punch press operation. The third lot hit the jackpot -- only 4.5% defective -- and it really looks like Penult can stop worrying about the terminal block job.

(Thanks to E.J.O'Brien)

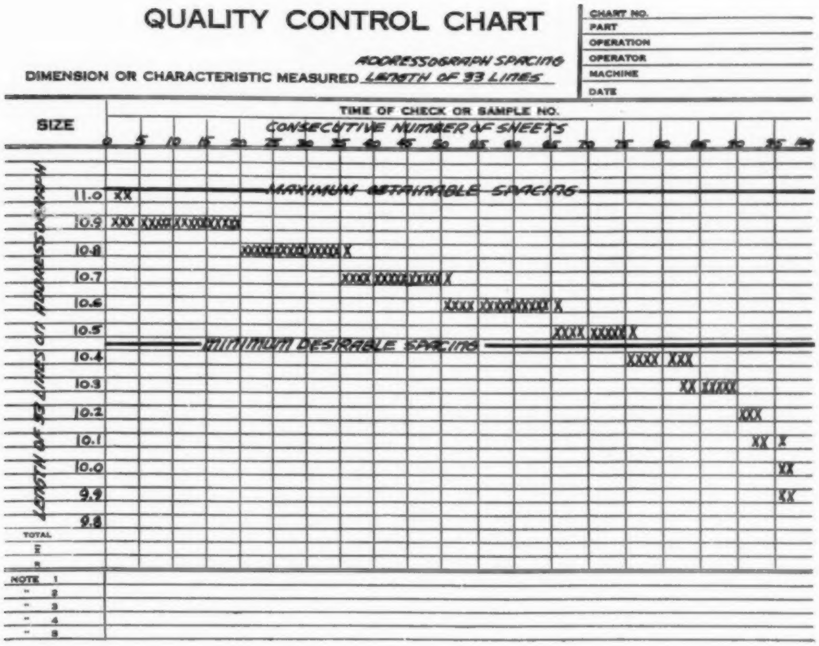


GETTING AT THE GUTS OF GANG GEAR CUTTING

Holding pitch diameter tolerances of 2.5 thousandths on gang-cut gears is no picnic even with a precision Pratt & Whitney profile gear grinder. For one thing, the gears are never quite round, so where do you take the measurement? The inspectors at the Prime Pump Co. seemed to know the answer; they rejected plenty of them for over/and under-size pitches. These losses were a chronic disease until the Q.C. boys came up with a multi-vari chart study, partially reproduced above.

Each of those lines shows the minimum and maximum of 7 diameter readings on a gear. The length, then, is the out-of-roundness and it isn't nearly as bad as everyone had thought. But look at the "trend" effect from the first to the sixth gear on the gang arbor. No one realized that. And look where the operator has his process set -- right out to the edge of the cliff. No wonder he falls off every now and then. Pictures like this are powerful; it convinced the operator to pull down his process setting and told him how much to allow for the "trend". The inspectors are having a hard time finding defectives now.

(Thanks to Maurice B. Ahern)



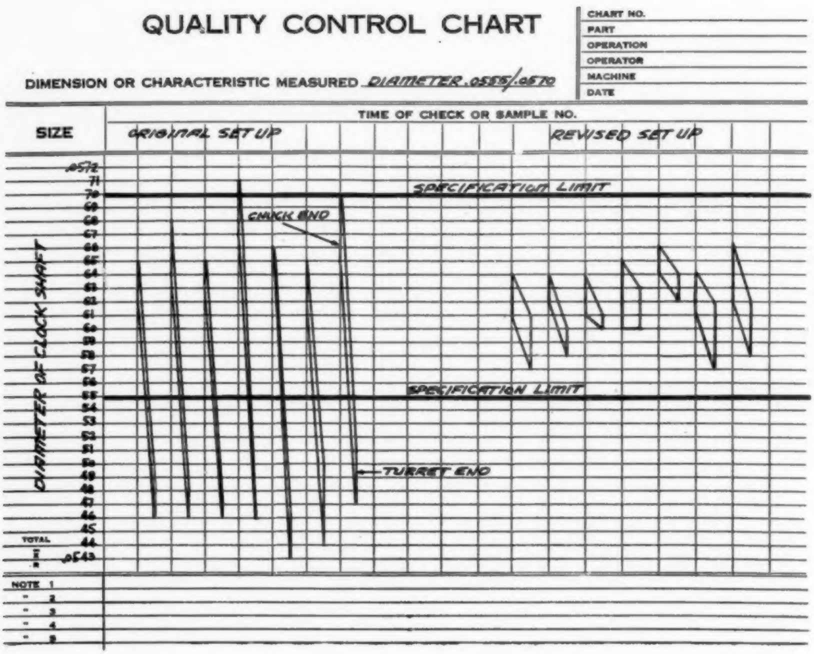
PREVENTION PAYS OFF AT PAYROLL

The unfailing ability of most payroll departments to come up with the right amount in your week pay envelope is not often open to question. But in one payroll department of a government agency, this long-held prestige was shaken by a series of inexplicable errors. Inexplicable, that is, until traced to errors of "registration" in the weekly "money list" used to make up the pay envelopes. In preparing this list, names of employees were stencilled on with an addressograph machine while the amounts due were typed on. Frequently, the line-spacing of the two machines did not jibe and, as the error accumulated, a man's name and his stipend could be separated by several lines. All this in spite of the protests of the addressograph operator who steadfastly maintained that she always set the spacing adjustment screw right when she started the weekly job.

The "right" spacing would give just about 10-3/4" for the 33 names stencilled on a page, since 33 lines of typing run that long. When a Q.C. minded investigator examined the actual spacing of the first 100 payroll sheets off the machine, he obtained the graph above. It was a dead giveaway for the slipping adjustment screw, like deertracks in the freshly-fallen snow.

A new adjustment screw restored the payroll department's sagging prestige. To preserve that prestige in the future, the addressograph operator now makes a periodic check of the money sheets as she prints them.

(Thanks to John C. Arnold)



IMAGINATION WITH CLOCKWORK

The hands of a clock are pressed on to the nose of the clock shaft and are meant to stay there, not fall off. But they were falling off at the Caldwell Clock Co. and it made everybody mad, -- the assemblers, the foremen, and especially the inspector who checked the spindle pieceparts at the automatic screw machine. He insisted he always carefully checked the end section of the spindles and that they were within the .0015" tolerance.

But an imaginative Q.C. engineer proved him wrong with the multi-vari chart pictured above (on the left). Although the end section was only .033" long the Q.C. man visualized the possibility of taper and checked each end of the section; the inspector had simply applied his micrometers to the whole section. Examination of the tool holder mounting hole in the turret head of the screw machine proved that it had worn egg-shaped and was causing the taper. An imaginative set-up man came to the rescue this time; by matching the out-of-roundness of a discarded tool holder to the out-of-roundness of the mounting hole, he was able to produce the multi-vari chart on the right. Until there was time to shut down the machine and re-bush the hole, this ingenious stunt stopped the flow of tapered spindles. Needless to say, the clock hands have stopped falling off and time has been saved.

(Thanks to George F. Mason)

References and Notes

(1) Juran, J.M., "Insure Success for your Quality Control Program", Factory Management and Maintenance, October, 1950.

(2) Juran, J.M., Quality Control Handbook, McGraw-Hill, 1951 page 102.

(3) It is seldom, of course, that management is actually hostile to the preventive philosophy, but the author knows of at least one instance where efforts to apply quality control techniques were unavailing because of such hostility. It occurred in a paper manufacturing company subsidiary of a large publisher. Because of this consanguineous relationship, top quality paper was sold to the parent company at cost price, whereas "seconds" -- sold on the open market -- actually commanded a higher price. Clearly, management of the subsidiary company had little incentive for adopting a preventive attitude toward defects.

(4) Juran, J.M., "Insure Success for your Quality Control Program," ob. cit.

(5) Juran, J.M., Quality Control Handbook, ob. cit., page 242.

(6) Feigenbaum, V.A., "Quality Control: Principles, Organization, Practices," McGraw-Hill, 1951, page .

(7) For explanation of Multi-Vari chart, see Seder, L.A., "Diagnosis with Diagrams," Part I, Industrial Quality Control, Vol. VI No. 4, January, 1950, pages 11-19, or Quality Control Handbook, ob. cit., pages 721-724.

(8) For a summary of various trouble-shooting techniques, see Seder, L.A., "A New Science of Trouble Shooting", Industrial and Engineering Chemistry, Vol. 43, No. 9, pages 2053-2059.

(9) For a more detailed discussion of the use of capability data, see Seder, L.A., "Quality Control in Screw Machine Operations," Quality Control Handbook, ob.cit., pages 704-716.

Examples of Vendors' Certification

August B. Mundel, Sonotone Corporation

A vendor's certification of the quality of his product should include the five items outlined by Mr. King. [1] This discussion shows an adaptation of vendor certification applied to a specific product. The Sonotone Corporation furnishes manufacturers of television picture tubes quality data on the electron guns they purchase from us. This example of vendor's certification has several aspects which are different from most certifications since the product cannot be individually evaluated except by use or destructive test.

Most of the products that are manufactured by the Sonotone Corporation can be tested for all characteristics at our plant and at customers' incoming inspection. The electron gun for the television picture tube is an obvious exception. The electron gun consists of a cathode and a control system. The cathode is the source of electrons, which strike and light the screen of the picture tube but the cathode cannot emit electrons until it has been sealed into the picture tube blank, the tube thoroughly evacuated and the cathode processed to convert its coating into the oxides which are emissive. The electron gun is the heart of a picture tube and therefore the loss per defective unit is large. The product cannot be tested individually before use in the tube. The customers processing can adversly affect the quality of the tube and be misinterpreted as the failure of our product, the gun and cathode. Due to these factors a lot by lot record is not as important as a continuous record with a good process average. Accordingly, emission checks were started on samples from each cathode lot and a process average for the product obtained.

Although the first electron guns manufactured and sold were satisfactory, manufacturing and selling guns in larger numbers produced some customer complaints. Despite our systematic checking of samples from each cathode lot, by sealing, exhausting, and processing random samples before releasing a lot to the assembly department, the customers began to question the quality of the cathode and gun in each unsuccessful or unsatisfactory picture tube. This led us to code each gun with the lot number of the cathode used in it and to record the lot numbers shipped to each customer.

Cathodes are not considered satisfactory at our plant unless they can be activated by a standard procedure. Still there are some variations which tend to make these cathodes process differently at the customer's plant. Lot numbers on each gun allowed the customer to process one lot at a time and allow for the lot characteristic in his process. Thereby our lotting system helps the customer use the gun more effectively. Where difficulty was encountered with a lot we were in a position to investigate the performance of the lot in our plant and in the plant of other customers and render the customer a service in helping him trace down trouble in his procedure which he might otherwise believe was due to cathode failure.

Customers' interest in our procedures has led us to furnish detailed information of our control process and the data on individual cathode lots. Sonotone electron guns have been built into more than a million picture tubes and hundreds of cathode lots have been processed. Despite the volume and the number of customers we have been able to keep each customer regularly advised on cathode performance.

When a customer's first order is shipped we write him about our practice and enlist his aid in correlating our results with his. Our first letter states:

> "We have recently shipped you some Sonotone cathode ray guns. The cathode lot numbers included in this shipment are clearly marked on each mount. It is our practice, not only to closely control the thickness of the cathode spray coating by accurate and systematic quality control methods, but also to check samples of each cathode lot for its emissive properties before releasing the cathode lot to the plant for assembly.
>
> The enclosed graphs indicate the emission readings obtained from our tests of cathode ray guns, which were aged and activated according to our Process Specification 060,078, a copy of which is enclosed. The readings we obtain are an average of 5 samples run on a trolley exhaust system and processed according to PS060,078.
>
> We send each of our customers cards, similar to the enclosed, and ask that they return the cards filled in to show what their beam current, cut-off voltage and gas readings are. We have asked each customer to take a sample of 5 guns from each shipment or carton and send us the data on the enclosed card, since it gives us information which we can more closely correlate with our own results. This, in turn, permits us to give a better estimate of how future shipments will perform.
>
> Will you kindly return information on this, your first shipment, and also similar data on samples taken from future shipments. We shall be glad to furnish you with additional cards as your supply dwindles.
>
> We are sure that this information has been of value both to ourselves and to our customers in reducing the possibility of low emission mounts turning up in finished picture tubes."

We follow these regularly with graphs showing the emissive qualities of all cathode lots on a variables graph. The graphs show minimum acceptable values for the average emission of the sample.

Our system of reporting quality to the consumer has many similarities to those discussed by Mr. King.

a. Classification of defects:
   A specific critical characteristic is tested by a destructive test.
b. Use of recognized sampling plan:
   Control chart technique, variables inspection is used.
c. An acceptable quality level:
   Although a definite AQL is not specified acceptable levels of emission are specified and the lot acceptance criteria are furnished the customer in the Process Specification.
d. A lotting plan adaptable to sampling technique:
   Each electron gun is marked with the lot number.
   Each lot is the result of a single manufacturing run.

e. Process average information in the producer's plant: Graphs are furnished to the customer showing the emission of each lot tested. Each graph may include 40 or 50 lots. Accepted and rejected lots are included.

Experiences

Customers have as a rule not returned post-card data, although some quality-conscious organizations have cooperated splendidly. We ceased mailing data to customers for a short while, but requests were received asking that we resume the practice and we decided to do so. Unjustified complaints of cathode failure have not been a cause for product return since this program was introduced. This, of course, is primarily due to the quality of cathodes although the publication of the data has been of real assistance. Publication of the data and the lotting system has caused blame to be placed on the consumers process when it was at fault. Had the information not been available the electron guns might have been blamed for the poor performance and returned. Thus the lotting system and data aids the customer as well as Sonotone. The most valuable result we have obtained from our practice is customer confidence. This has fostered the growth of the operation.

Conclusion

We believe that certification has a definite value since it furnishes the customer information which is not obtainable except by an involved incoming material inspection procedure. This information assists Sonotone customers to do less incoming material inspection and still have adequate knowledge of the product received.

The entire aim of vendor certification is a reduction of the incoming material inspection load without sacrifice of quality assurance. Good inspection practice can do some of this by using reduced sample sizes. An even greater saving can be realized if the incoming inspection service is alerted when process averages are marginal so that more rigorous inspection plans can be placed in operation to prevent sub-standard parts from passing to stock or to the assembly line. We believe that the plans discussed herein and by Mr. King implement this purpose.

We are firmly convinced that the organization that furnishes adequate quality reports on its product is doing a worth-while service to the customer. It is the intention of Sonotone to continue this service and to encourage our vendors[2] to furnish quality certifications of this type to us.

References

1. Vendor Certification	M. E. King	This Volume
2. Narrowed Limit Gages	Ellis R. Ott and August B. Mundel	This Volume

THE CONSUMER-VENDOR RELATIONSHIP - A MUTUAL RESPONSIBILITY

J. Philip Worth
Electrolux Corporation

Since the beginning of the Korean conflict, modern industrial plans for the expansion of domestic lines have been exploded. A new concept for industrial activity has arisen which is phrased the "guns and butter" program.

In this new program untested theories for the proper allocation of limited basic materials have been put into effect. Material allocations have affected both military and domestic consumption. As a result consumers and vendors are faced with the confusion of unpredictable material deliveries. Such confusion can so impede the natural flow of goods as to lead to material substitutions, relaxed standards, lowered inspector morale, and even an independent attitude on the part of some purchasing agents and vendors.

From my observation, there are many people who are vitally interested in the far reaching effects of this program. Those who have outstanding interest are:

1. The purchasing agent who has to buy a conforming product at the right price, in the proper quantity, and on schedule.
2. The vendor who has to deliver as the purchasing agent requests.
3. The quality-control manager who must deliver only uniform conforming products to the production departments.

Of these, the quality control manager, although listed in third place, is the most affected. This is because he is in the middle of a conflict. When he rejects material he is plagued with complaints from management, who sometimes use higher authority to accept the rejected lot. When materials are accepted which do not adequately conform, the complaints originate from the production departments. In addition, sometimes the vendors allocations for rejected material are restricted and they cannot be replaced.

When such conditions arise, the quality control manager can put into action the executive skill for which he has been trained. He is also ideally situated where he can improve his own position and be an important link between consumer and vendor. This should be done by a carefully planned program of consumer-vendor liason for the promotion of mutual progress and responsibility.

There are several companies who now have established plans for quality liason between consumer and vendor. The merits of these will not be discussed here, because the purpose at this time is to reopen the consumer-vendor relations subject for the whole society. With this in mind I therefore propose to discuss:

1. The quality-control manager as the key figure.

To briefly state this condition, the quality control manager:

a. Knows the specifications of the material.
b. Has provided the inspection plan and testing equipment.
c. Is familiar with the fabricating operations and end use of the material.

d. Receives first hand detailed information on all materials received.

e. Can review inspection data with the purchasing agent.

f. Will request detailed information of vendor processes from the purchasing agent or vendors representatives.

g. Can receive permission to inspect vendors facilities to aid in solving mutual quality problems.

h. Provide liason between consumer and vendor for quality control purposes.

i. Establish an effective control at the vendors plant.

j. Can reduce consumers inspection expenses as vendors quality improves.

2. A case history showing the development of mutual responsibility in seven natural steps.

Shortly after V-J day, Electrolux realized that the 1940 manufacturing plan would not produce the maximum quality and quantity required by its sales department, except at a substantial increase in unit cost. One of the outstanding examples was the routine of receiving inspection, machining, finishing, and assembling of die castings purchased from the Doehler-Jarvis Corporation.

Prior to World War II, parts were cast by Doehler and used by Electrolux on a relaxed production schedule and at lower labor rates. Conditions of that type provided a relaxed atmosphere when handling quality fluctuations. When contact was required, it was considered a function of a purchasing department employee or his delegate. Contact was conducted through the Doehler sales department, by phone or letter, and in due time the adjustments were made. With the expanded production, faster action was required on quality variances.

First Step - Quality Department Enters Consumer-Vendor Relationship.

The quality department being familiar with the type, variety, and magnitude of variance, was requested to take action for faster permanent correction. The entry of quality personnel was made through the Doehler Sales Department with permission to work directly with manufacturing personnel from the Plant Manager down.

Second Step - Consumer-Vendor Quality Agreement.

During the first meeting at the Doehler plant, the conditions of quality variance were discussed in detail to show why corrections were required. In addition, Electrolux outlined a plan for liason by installation of our inspector who would be in first hand contact with all phases of the quality function in both plants. These were accepted as fact, but without too much enthusiasm because of past history and a normal resistance to change.

Although the idea of the inspection plan was accepted, much effort had to be applied on new quality standards. These were finally agreed upon, final inspectors trained, and the quality level of shipments to Electrolux immediately started to improve. This was carried out on several parts simultaneously.

Third Step - Consumer-Vendor Shop Orientation.

By former methods this would appear to be the end of a job, but present standards of management, increased production methods, etc., show that at this point mutual responsibility begins. With this in mind, the Plant

Manager was contacted to discuss the complete orientation of key personnel and the elimination of rejections at the Doehler Plant. Upon agreement, the Plant Manager, Casting Division Superintendent, Chief Inspector, and others visited at Electrolux for full knowledge of our processes, with particular emphasis on one part which was re-selected for reject elimination.

Fourth Step - Consumer-Vendor Job Selection.

The first part selected was our cleaner front cover which requires a fine finish and acts as a mechanical base for opening and closing the dust bag chamber. The records showed that rejections were approximately 1.5% total for break-outs, warped castings, dented castings, and incorrect hole location. Warped and dented castings were traced to improper handling starting from the casting machine, and on through the method of shipment. Handling methods were adjusted to prevent warping and denting. Breakouts were improved by reorientation of trimming tools, but were not eliminated. Despite the efforts on breakouts and more vigilance on the "boring of the hole" location, rejects continued.

Fifth Step - Consumer-Vendor Methods Analysis and Correction.

All the Doehler dies and processes were again mutually reviewed for elmination of rejects. After discussion, it was decided to change methods in two stages: first, to correct the boring; and second, to avoid breakouts.

An analysis of the boring operation revealed that the cover was placed in a nest and located from an "air-fit" type of projection as shown in Figure 1. This located the position of the bored hole which varied by the position in the one nest used to accomodate parts from several dies. No thought has been given to the relationship of the bored hole to the five mounting posts. Immediately it was decided to provide a new fixture which would use the mounting posts as a locating medium for boring. Figure 2 shows new fixtures for locating on 5 posts. Figure 3 shows fixtures with covers ready for boring. When this was placed in operation, it immediately solved this cause of rejection.

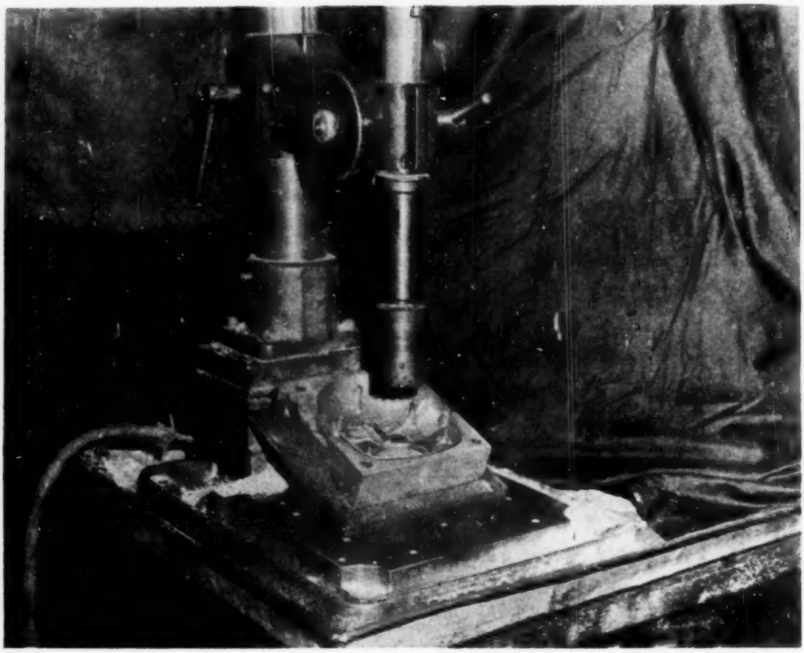


FIGURE I

To elminate breakouts required more extensive alterations. Ultimately the casting dies were reworked to furnish a deeper casting. A new method of facing-off the excess metal was established to obsolete the die trim method. Figures 4 & 5 show two stage method of die trim flash removal which is now obsolete. Figure 6 shows new combined method of die trimming and facing. As a result of these activities, rejections have now reached .2% total on this part. Rejections on other parts have also been reduced by a similar approach.

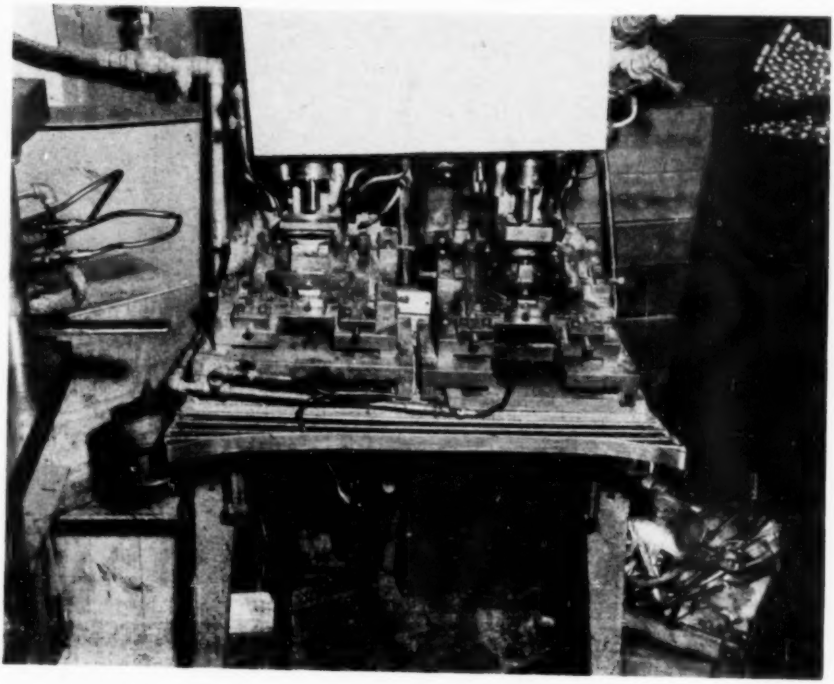


FIGURE II

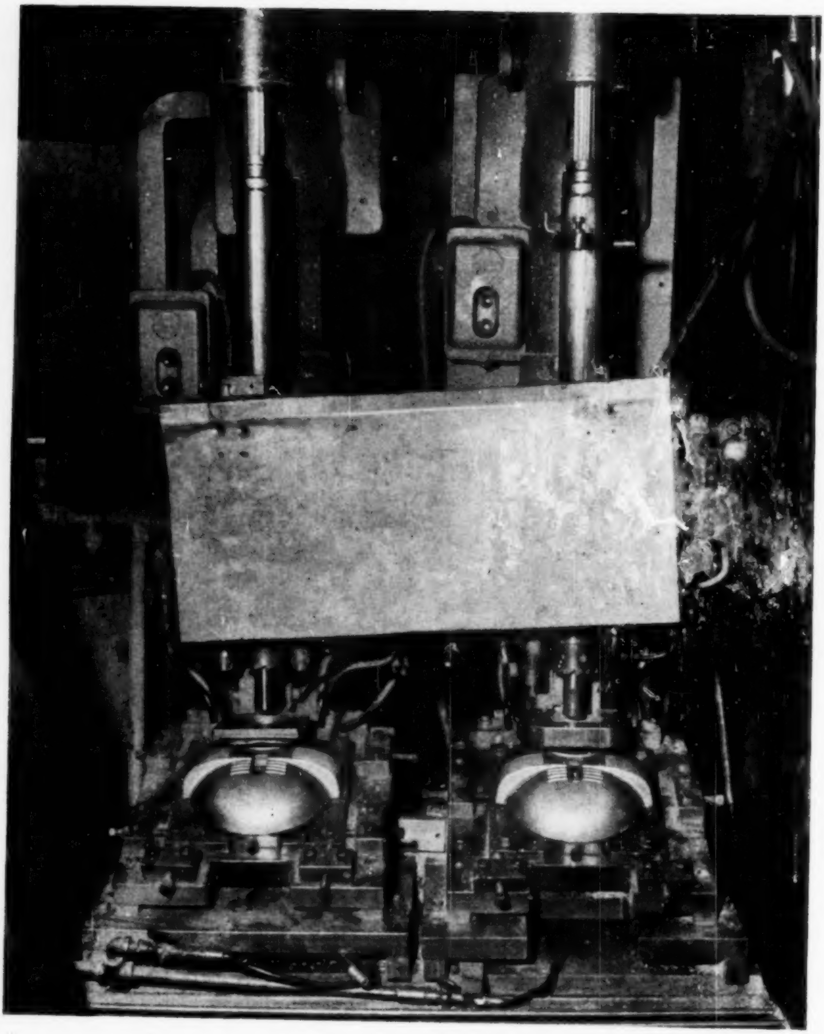


FIGURE III

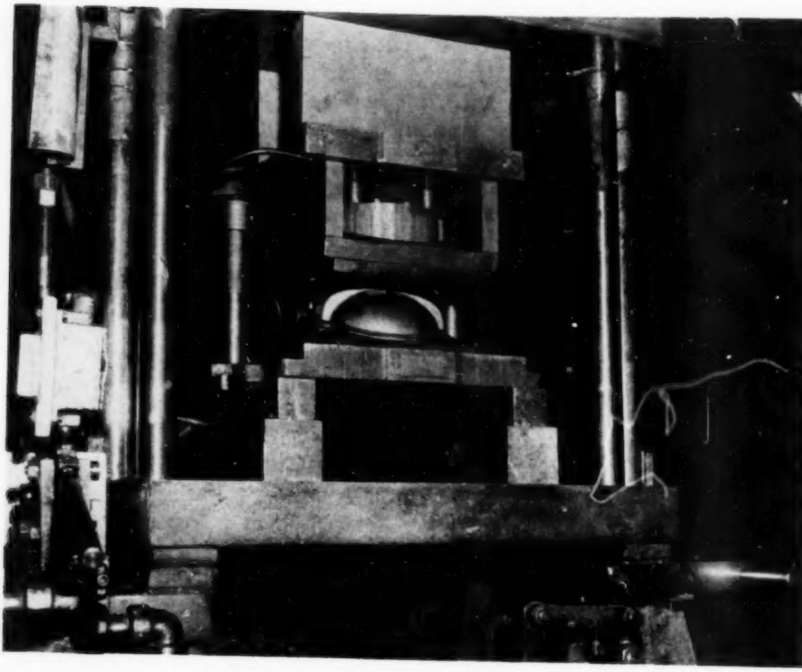


FIGURE IV

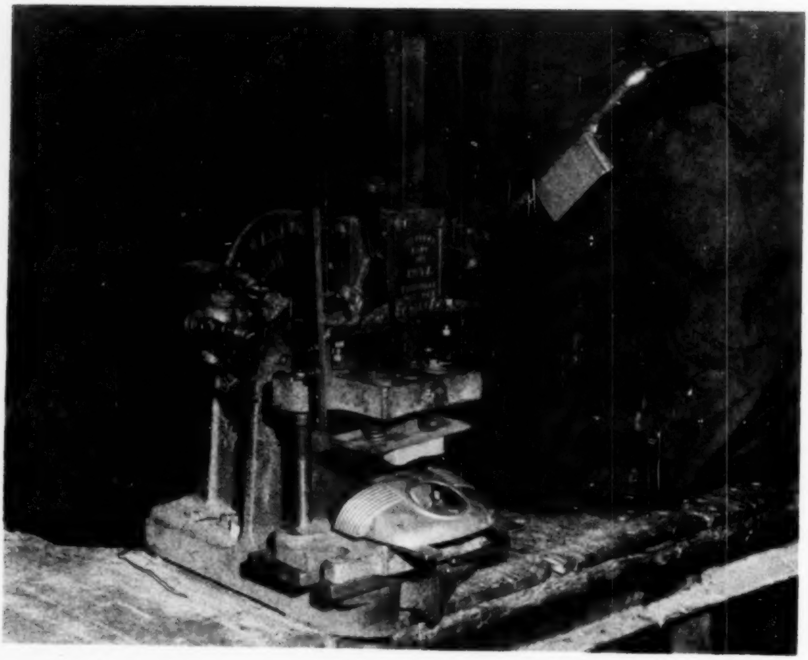


FIGURE V

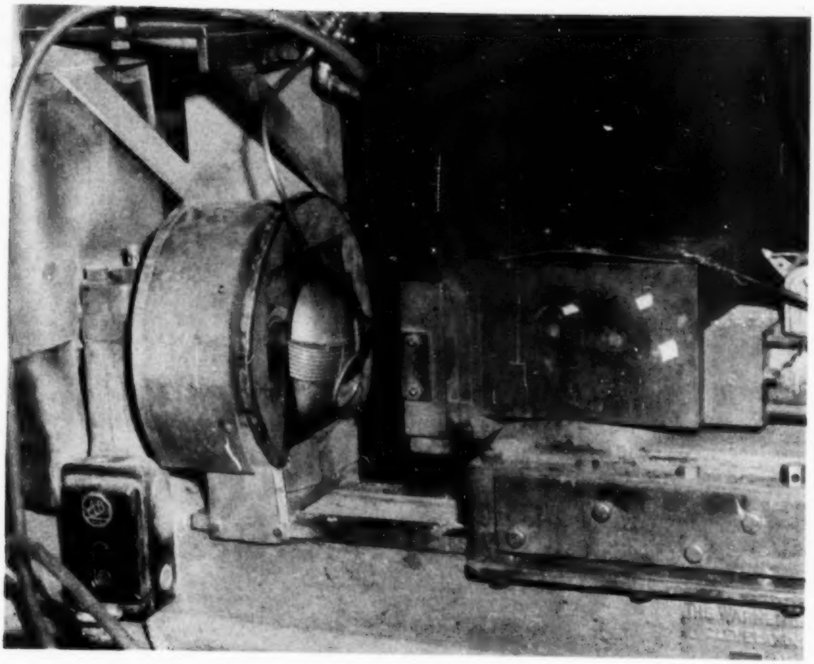


FIGURE VI

Sixth Step - Consumer-Vendor Preventative Inspection.

In addition to this illustration, several preventative inspection ideas have been adopted. The most important of these is a parallel inspection plan for checking new dies and fixtures. In this plan, Doehler makes a sample inspection from all new tools, records its findings, and submits findings and sample parts for Electrolux to check. Using the same approach and gages, Doehler findings have been duplicated many times. After this work is done, the report is submitted to the Engineering Department for final approval before this die is placed in production.

Seventh Step - Consumer-Vendor Sampling.

Sampling of Doehlers shipments starts at the Doehler plant where the shipper selects a random sample of each part, codes it, and places it in the shipment to facilitate easy handling at Electrolux. Upon receipt of a production shipment, the pre-selected samples are immediately sent into the Electrolux production line. These are given the regular production treatment with a report of findings for each operation on a prepared form which is returned to the receiving inspection station. Receiving inspection uses this form as their guide for inspection disposition of the shipment.

From these brief illustrations one can see that team work has been established and that product responsibility has been mutually assumed. Costwise, Electrolux has borne the cost of liason while Doehler has provided improvements in methods and tools at no cost to Electrolux. From a quick analysis of the one case illustrated, both companies can point to a $5,000 annual saving, due only to the reduction of rejects from 1.5% to .2%. The .2% figure may also be reduced but at some time we will reach the point of no return. An illustration of another mutual gain which was realized by this case study is exemplified in Figure 7. This photo shows the layout for gate breaking on machine 33, with boring operation on the other machine.

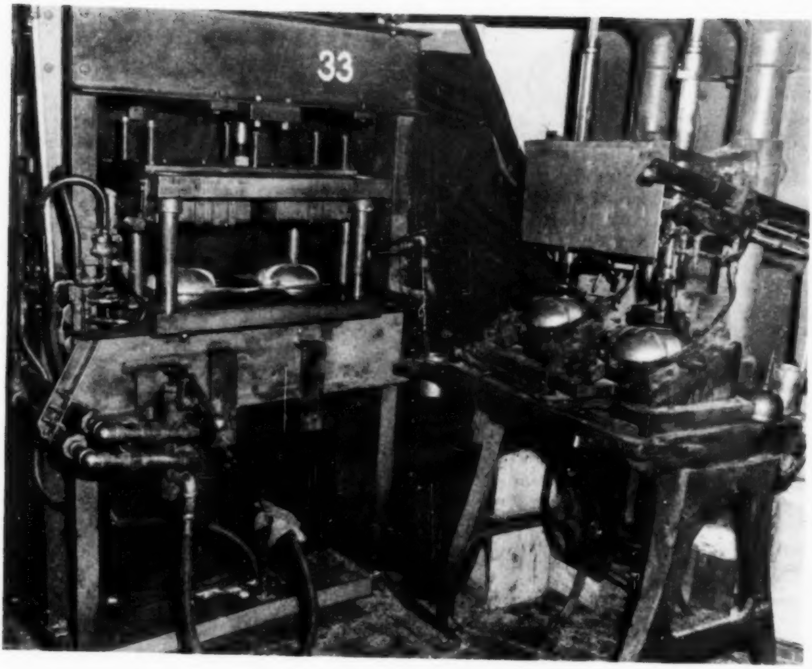


FIGURE VII

Both machines are operated by one person, whereas before the study there were a minimum of two people and sometimes more were required to perform these operations. Using the same steps, other mutual consumer-vendor applications have been made in the plastic, rubber, metal fabrication, and appliance fields.

3. A suggestion to all local chapters.

Prepare a message for delivery to all local members which will emphasize the consumer-vendor problem. Point out that most quality control men can only control the material which passes through their hands. The other two "M's" are under the control of the foreman (men) and the engineer (machine). A series of round table discussions would level the sights of members on the subject. In this fashion enough interest could be generated so that consumer-vendor relations should have a firm place in the yearly calendar of activities, and would take its place with other subjects for a monthly meeting topic. For these meetings, select speakers who are now using consumer-vendor programs.

4. The development of an industry-wide technique.

As the mighty oak springs from the acorn, so will the consumer-vendor technique grow. The national officers should sponsor this subject and promote the pooling of ideas. The final results from this pool of ideas could be incorporated in a standard procedure which, in due time, would be universally accepted as good business practice. Such a technique should be concise but broad enough to cover all industry and should be pointed toward control of purchased materials without interference with the perogatives of the purchasing agent. In order that this subject be given proper treatment through the years, it is suggested that the national officers sponsor and form a standing committee to cover consumer-vendor relations.

THE USE OF AVERAGE AND RANGE CHARTS TO CONTROL MATERIAL CONSUMPTION

Howard R. Bolton
Harrison Radiator Division, G.M.C.

Average and range charts are frequently used in industry to control the dimensional accuracy of a piece or product. Parts are taken from a machine and checked with micrometers or some other measuring instrument and the dimensions are noted on a chart. Average and range values are computed and plotted on control charts. This procedure will tell us if the operation is in a state of statistical control. We say an operation is in statistical control if the variation is due to chance causes alone. The control chart will also tell us if the process is in control at the right level. Do our average values form about the mean of the specification? Are they at the high or low limit of the specification, or are they outside of the tolerances established? The control chart is also used to detect trends. Are we drifting away from the desired average? The average and range charts can be used to analyze practically any process where direct measurements of weight, volume, or linear measurements are used.

During the latter part of 1950 our Statistical Control Department became involved in a discussion regarding solder consumption on radiator core assemblies. Solder consumption figures are established by the Production Records Department and are used as a basis for ordering material. It was found that the actual solder consumption in the various core departments was exceeding the figures established by the Production Records Section. Sample lots of material were checked throughout the production processing. In most instances it was found that the average solder consumption was above that allowed in the specification. During the course of analyzing the data, a simple graph was constructed where the weight of solder consumed on each individual core was plotted. These values were plotted in the order in which the checks were made. The resulting charts showed in all cases that there was a downward trend throughout the test run. We believed there was sufficient evidence to warrant a quality control program to determine if the solder consumption could be controlled and at what level.

The decision to institute a quality control program on the solder consumption was not based entirely upon the fact that there was a difference of opinion regarding the standard established. We also took into consideration the fact that solder is an alloy of lead and tin, and during the latter part of 1950 tin was becoming a very critical item. We also gave consideration to the fact that solder is an expensive material and any saving in solder consumption would be substantial.

Radiator cores are made of copper. The various tube and center assemblies are stacked into core blocks, and the core blocks are securely held in place by frames. The frame holding the core block is run through an automatic soldering dip. This solder dip cleans the copper by immersing in flux and the core is soldered by dipping the core block in a pot of molten solder. This process is then repeated on the opposite side of the core. It was decided that we should weigh the core and frame assembly prior to, and immediately after, the dipping operation. The difference in weight would indicate the amount of solder accumulated by the core during the dipping operation. There are five radiator core dips in operation and each core dip is working two eight-hour shifts. In order to accumulate the data required, we assigned one inspector on each shift. It was this inspector's responsibility to get one sample each hour from each of the radiator core dips. These weights were recorded on forms provided. At the end of each

eight-hour period, we had the actual weight of solder consumed on eight individual cores. This data was turned in daily to the Quality Control Office. The Quality Control Office computed the average and the range for each sample of eight cores. These points were plotted on average and range charts.

The control charts were located at each radiator dip. In Figure 1 you will note an average and range chart for one radiator dip. This dip we have designated as Face Dip No. 3. On the chart, you will notice that we have plotted one point for each day's production. Separate charts were kept for each of the two respective shifts. The charts we have illustrated were taken from our regular production run from December 1950 through the middle of May 1951. You will note that during the months of December and January there was a decided drop in the amount of solder being consumed. The average for the month of December 1950 was 3.95 lbs. per radiator. During the month of January 1951, the average had dropped to 3.62 lbs. per radiator. Each succeeding month shows a slight reduction in the amount of solder consumed. The latest average figure was 3.41 lbs. per radiator during May 1951. The process since that time has been holding very closely to the figure of 3.41 lbs. per radiator.

You may rightly wonder what caused the sharp drop in the amount of solder being consumed. You may also wonder what redesign was made of the core or of the dip equipment to allow us to reduce the amount of solder being consumed. I can truthfully say that the only expense accrued throughout the program was that of gathering the data. This involved one inspector on each of the two shifts. The reduction in solder consumption was not made by the Quality Control Department. We merely indicated the progress being made. Any reduction in solder consumption can be traced back directly to dip operators and to production supervision in the various departments. The Production Foremen were definitely in favor of this program. They would naturally have a vital interest in it, inasmuch as their performance is indicated by the control they have of the productive labor and materials and equipment they are responsible for. We found that the dip operators were very glad to get this information. It gave them a running picture of how well their dips were operating. We found that they took a more active interest and pride in the job they were doing. They paid closer attention to the dip and made more frequent checks on the depth of solder and the temperature of the solder being used. We found that they could control more closely the depth of the solder in the dip by more frequent cleaning out of the overflow vent. This they performed religiously.

The cost savings I believe speak for themselves. In Figure 1 you will notice a scale along the right-hand side of the average chart. We have used a base period of the December 1950 average and called this zero. Any reduction in the average value below this has been shown on this scale. You will note that the latest average of 3.41 lbs. per core means a saving of approximately $621.00 per day from this one dip. When you consider that at that time we had five dips in operation and the only expense involved in accumulating this data was 16 hours per day inspection time, plus approximately one hour quality control time, I think we can safely say this program has paid its own way.

During the period of April and May 1951 a series of quality assurance tests were made in conjunction with the solder consumption program. The purpose of this investigation was to assure us that we were not reducing the quality of the radiator cores being produced due to the fact that we were using less solder. This investigation involves a close check on the number of small seeper face leaks which are found on radiator cores prior

to the test and repair operation. This is a normal production repair operation required on all radiators. During this two-month investigation we did not find any deterioration of quality in this respect. A close analysis was made of the percentage of solder bond being obtained with these lower solder consumption figures. Our analysis disclosed that the solder bond values were consistently running high and there was no measurable difference in the heat dissipation of the cores with the later solder consumption. Based on these analyses we definitely proved that the reduction in solder consumption had not affected the quality of the finished product in any respect.

The material situation today is even more critical than it was back in December 1950. We believe 1952 will continue to be a critical year for many types of material. We bring this story to you not to say "look what we have accomplished" but merely to point out to you that many times the control you are looking for can be found in the simple average and range charts.

We hope our discussion today may show you one more tool you can use in your never-ending job of trying to stretch your supplies of critical material. Our story has been very simple, and I am sure that if you look at your processes you will find places where this tool can be applied in your organization.

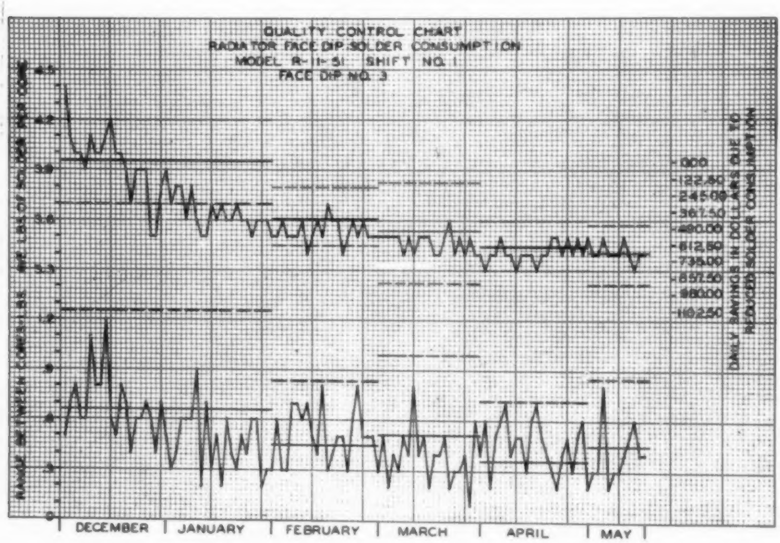


Figure 1

FOUNDRY QUALITY CONTROL

A. A. Evans
International Harvester Company

By designating this topic "Foundry Quality Control," I do not in any way want to imply that Quality Control in the foundry is basically any different that it is anywhere else. It is still the study and control of variables. The only difference that I have been able to establish is that in the foundry we have less control of our variables than they do in other industries. This lack of control has existed because the present day foundry stems from an art that, at one time, was covetous and secretive. The advent of mass production forced the change. Foundrymen began to share their knowhow. The transition took place and the foundry almost kept step with other industries. When they started to write books on the foundry, it was found that there were too many diversified ideas. The A.F.S. started its handbook in 1932, and it is still very incomplete. Great strides have been made in metallurgy and foundry engineering but we have still retained this hidden lack of control. It has been overshadowed by the rapid progress. We have grown to accept it as part of Foundry Practice. It has taken the form of the unwelcome visitor who is tolerated because we do not know how to throw him out.

Our present knowledge of Foundry Practice is derived from the trade secrets of melters and molders. Through the long tedious process of trial and error, our present day foundries have been built, and this inherent lack of control has been incorporated in the practice and accepted as such. For instance, we take an iron sample every hour but we don't get the result until the next day. When we get into a shrinkage condition, it sometimes takes weeks to correct. The enormous amount of money we spend cleaning and repairing castings is evidence of lack of control.

What I am getting at is that we cannot control Foundry Practice merely by changing a tool setting. We don't have a dial indicator on the cupola that tells us the analysis or the condition of our iron.

To eliminate this lack of control, we have to make functional changes. We have to find and devise methods of control. We have to change our way of thinking in order to eliminate intuitive decisions that have caused so much trouble in the past.

We have exhausted the trial and error method. The scientific method is inadequate because you can observe only one variation at a time. Therefore, we must have some method of study that can incorporate a vast amount of variables and control their end result.

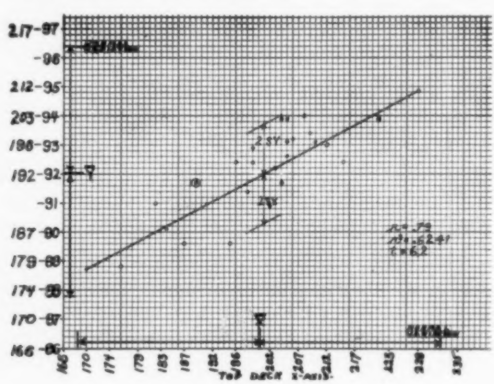
Now most any foundryman can tell you right away that this is impossible. There are just too many variables. They can reel off a list of reasons a mile long: -- green strength, hot strength, retained strength, grain size, contamination, green compression, permeability, flowability, moisture content, analysis of scrap and pig iron, size of scrap and pig iron, coke size and contamination, charge mix, weight of charge, hot blast heighth of coke bed, rate of melt, core hardness, core tensile strength, moisture content, amount of core gasses, analysis of melt, mold hardness, mold finish, rate of pouring and humidity. Believe me this can go on forever. But the truth is that every one of these are variables and Quality Control is the study and control of variables. We can therefore conclude that Quality Control by statistical methods will work in the foundry or any

place where we have repetitive processes.

It is important that we all realize that the foundry is virgin territory as far as Quality Control is concerned. There are so many questions to be answered. We are attempting to answer these questions through the medium of Statistical Methods.

As an example, about a year ago we were asked by engineering to maintain at least a 190 B.H.N. in the cylinder bore of our silver diamond engine block. Now the specifications for this block are 170 to 223 B.H.N. on the top deck. We had been brinelling our blocks and knew that we were fairly well within our specifications. But this 190 bore hardness had us stumped. We knew that the various sections of the block varied in hardness according to their structure and position in the mold. We also knew that it was a fallacy to speak of a hardness of a piece of cast iron. There is too great a variation within one piece. It is necessary, therefore, that we speak of the average hardness of a piece. What we had to know was the relation between the top deck hardness and the bore hardness. Our laboratory had its routine hardness checks but we realized that if we wanted an actual controlling factor, our study would have to be made under the adverse conditions in the foundry, not under laboratory conditions where they could surface grind before brinelling. In our present setup, we have to spot grind freehand before brinelling. We took random blocks taking the average top deck hardness and the corresponding average bore hardness. We made a correlation study.

CORRELATION OF THE HEAD FACE HARDNESS
VERSUS
THE CYLINDER BORE HARDNESS OF MOTOR BLOCKS



Previous to this study, the relationship between top deck and bore hardness had been doubtful. By applying Statistical Methods, we have established that the relationship is real and constant enough for reliability. From this study we find that the top deck will have to be held above 196 B.H.N. in order to maintain at least a 190 bore hardness.

In conjunction with this correlation we had to run another study to determine the relationship between top deck and the pan rail. We knew that was the hardest part of the block. We had to be sure that by increasing the hardness of the block, the pan rail would still be machineable.

We then established desired specifications of 196 to 223. Then all we has to do was to find out how to make blocks within that specification.

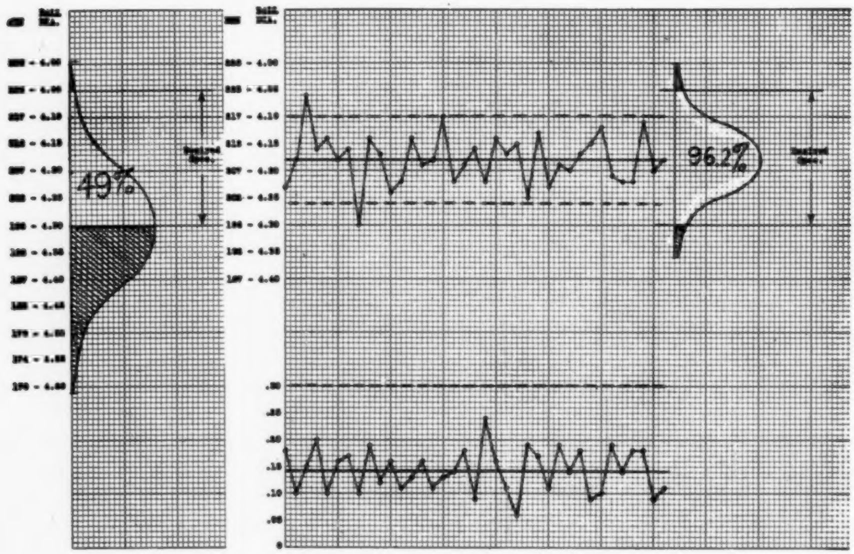
Our chill test was the only characteristic that we could observe, while the metal was in the molten state, that would give us an indication of the physical properties of the casting. So we made a study of the relationship between chill depth and hardness. We found that we would have to hold our chill between 4.5 and 5.5. This was much higher than our regular run of base iron. Also we would have to use alloy additions to maintain this chill. We do not make a constant alloy addition, we vary the amount of alloy according to the chill.

In order to properly control this addition of alloy, we had to develope a chart that would show the chill test operator just how much alloy to add for a given chill. A chill test gauge was also developed so that we could read the chill in smaller increments of measure. We had been measuring the chill depth with a scale. Our units of measure were thirty seconds of an inch and we guessed at the sixty-fourths of an inch. By using this new chill test gauge we were able to read the chill in a quarter of a thirty second of an inch, or, units of .0078 of an inch.

OPERATOR USING CHILL TEST GAUGE
AND
CHART TO CONTROL ALLOY ADDITIONS

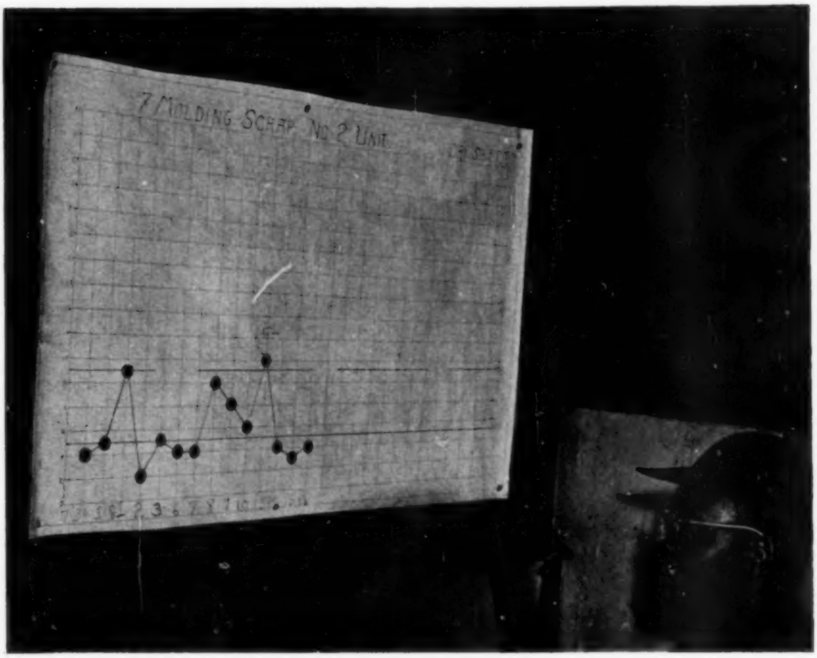
The result of this new method of controlling hardness is shown in the comparative graphical picture on cylinder block hardness. The historiogram on the left shows the process as it was. Almost all of the blocks were within the blue print specifications but only 49% were within the desired specifications which would have to be held in order to maintain the required bore hardness. The chart and historiogram at the right of the picture shows the process after the new method of control was installed. 96% of all the blocks were within the desired specification.

CHART SHOWING THE SPREAD OF HARDNESS IN MOTOR BLOCKS
AND
THE PERCENTAGES WITHIN SPECIFICATIONS BEFORE AND
AFTER THE PROCESS IS CONTROLLED BY STATISTICAL METHODS



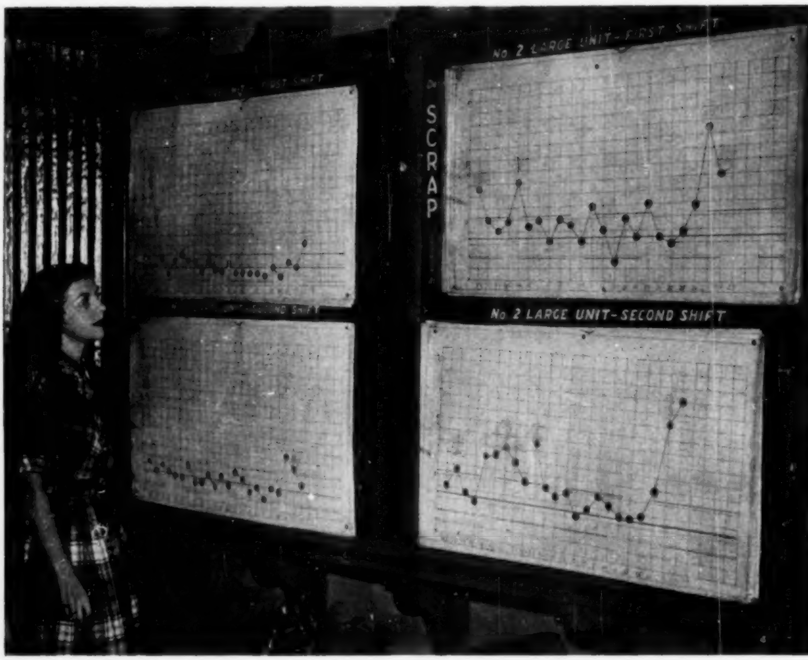
It has been the practice in the past that in the installation of a Quality Control Program to pick only the applications which we were sure would succeed. At the start of our program we had no choice of what to start on. We were right in the center of a very critical scrap period. We had to start on scrap. The first step was to take the regular circulated scrap reports and break them down as to the department at fault and to present the results in a graphical form. As an example: The scrap actually caused by the molders was plotted on charts which were hung at the molding units.

PERCENTAGE OF SCRAP DUE TO DEFECTS
MADE AT THE MOLDING OPERATION



The principal excuse for the high scrap had been sand, however, when the causes were broken down and presented it was found that each department shared proportionately in the high scrap. By bringing the facts into the open and presenting them to the men who actually control the scrap, the molders, coremakers and the iron pourers, a very drastic reduction in scrap was accomplished.

PERCENTAGE OF SCRAP CHARTS LOCATED IN
THE FOUNDRY SUPERINTENDANTS OFFICE

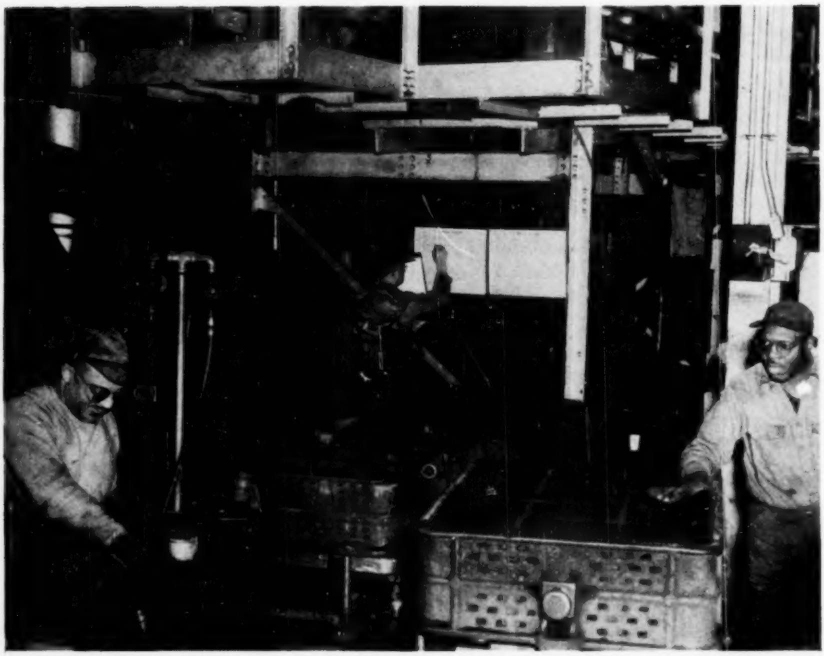


In the modern mechanized foundry there is very little opportunity for the individual molder skill to be of any great value. The modern foundry is one continuous machine where the individual is part of a hot sweaty mechanism. His part is monotonous, repetitious and very dull. The type of person who can stand such a job does not have to be a genius, in fact, it is much better if he isn't. There is one thing however that is inherent in all men. They are all proud; proud of some accomplishment, their family, their strength. But someplace along the line most of them have lost something; their pride in workmanship. Management has realized this for sometime. Various types of incentive plans have been tried, some with relative success, but all lacking in one thing. They failed to give the individual a record of his accomplishment. A record out in the open where everyone can see it.

In one of our first foundry applications of Statistical Quality Control we realized we had the answer. A chart placed on the job to record the mans skill and ability. On one of our crankcase castings where two are made in a mold, patterns number 1 and 2, we were scrapping a considerable number because of a swelled condition on the drag side. A chart of the $\bar{X}$ and R type was placed on the job and a standard type mold hardness gauge was used to record the hardness of the molds. On this job there are two men who ram the molds and they alternate each hour. This gave us a splendid opportunity to create competition between men. On our chart we recorded mold hardness in different colors for each mans work. When one man saw his mold hardness was less than the other mans he would immediately try a different method of ramming to try to beat his fellow worker. This went on for a few days and the mold hardness was brought up and the number of scrap castings became less. At this time we became aware of the fact that the scrap on number 1 pattern had been eliminated and what scrap we were getting was coming from one pattern of each mold, Here we had to change our chart plan and two charts were placed on the job to record the hardness of each pattern separately. It was found that the hardness of number 1 pattern side of the mold was much greater on the average than number 2 side and both men were running the same pattern of variation. Then we knew there was a difference in the operation. It was found that the man was reaching across number 1 pattern which is a long reach and was just a little more awkward in ramming the far side of the mold. This was corrected and the hardness was brought up. Now we have completely eliminated scrap from the swelled condition on this casting and the men are proud of their accomplishment.

QUALITY CONTROL CHECKER CHECKING
THE HARDNESS OF A MOTOR BLOCK MOLD

QUALITY CONTROL CHECKER PLOTTING THE MOLD HARDNESS ON AN AVERAGE AND RANGE CHART



In the production of most six cylinder automotive blocks, the heavy barrel core or body core which form the crankcase and cylinder bores, is made in an open face four part core box. A sand slinger is used to fill the box with sand, then butt rammed to increase the hardness. The particular barrel core that we are going to talk about stands rather high (20"). It sits on a flat plate while being baked. Because of the heighth of the core and its upright position while baking, it is necessary that we have a well rammed core with considerable green strength to prevent sagging.

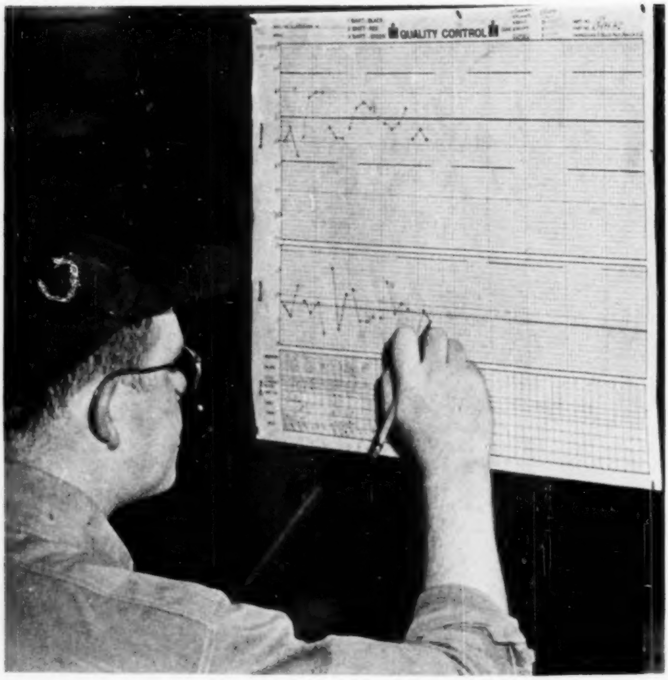
Quite often sagged barrel cores would be delivered to the molding unit. When these cores were set in the mold they would shave or crush the green sand causing scrap. If the sag was detected then the cores would be rubbed to fit. When rubbed cores were used the tendancy was to rub them too much, leaving heavy fins on the castings.

This condition of sagged cores had existed for a long time and the correction could not be expected over night. A statistical study was made of the green core hardness. Some difficulty was experienced in getting reliable readings with a standard mold hardness gauge. The small base plate of the gauge was not large enough to prevent the gauge from being tipped. The gauge was modified with a base ($1\frac{1}{2}$" x $1\frac{1}{2}$").

QUALITY CONTROL CHECKER CHECKING THE
GREEN CORE HARDNESS OF A CRANKCASE CORE

After this modification was made a more reasonable pattern of variation was observed. When plotted on an $\bar{X}$ and R chart, the pattern appeared quite normal, but the average, or $\bar{X}$, was rather low (about 43). By using the chart as a guide the man who butt rammed the core was able to increase the average hardness to 55. The harder cores did not sag. An $\bar{X}$ & R chart was set up on the job, figure ( ), shows the core being checked for hardness by the Quality Control checker. Figure ( ), shows the green core hardness being plotted on the chart, which is placed right on the job where the operators can see it. Since this hardness was raised there has been very little scrap caused by sagged cores.

QUALITY CONTROL CHECKER PLOTTING THE GREEN
CORE HARDNESS ON AN AVERAGE AND RANGE CHART



For quite a long time foundries have been trying various types of incentive plans to insure the production of quality castings at low cost. Prior to World War II, there was an abundance of skilled coremakers and molders. In most shops where piece work prices were used the quality was part of the rate. They paid for nothing but good cores or castings. When the war started and skilled help became scarce the quality standard was lowered in order to meet production schedules. Cores which would have normally been scrap were patched. This patching of cores grew into accepted practice. The amount of casting salvage also increased and an increase in cost followed.

After the war it was found that these precedents which were set during times of emergency had become standard practice. In order to correct this condition some foundries went so far as to pay extra bonus for good quality of castings and cores.

We believe that we have the answer to this problem. Through our Quality Control department we have been able to set up a system of checking the quality level of our coremakers and squeezer molders. Each of our coremakers who work on the more delicate and expensive cores, such as water jackets for cylinder blocks and heads, are rated at least twice a day. These ratings are based on the quality of sample groups of cores and plotted on charts right at the coremakers bench or machine.

A similar system is used on molders.

CHART SHOWING THE COREMAKERS PERCENT
OF EFFICIENCY IN MAKING CORES

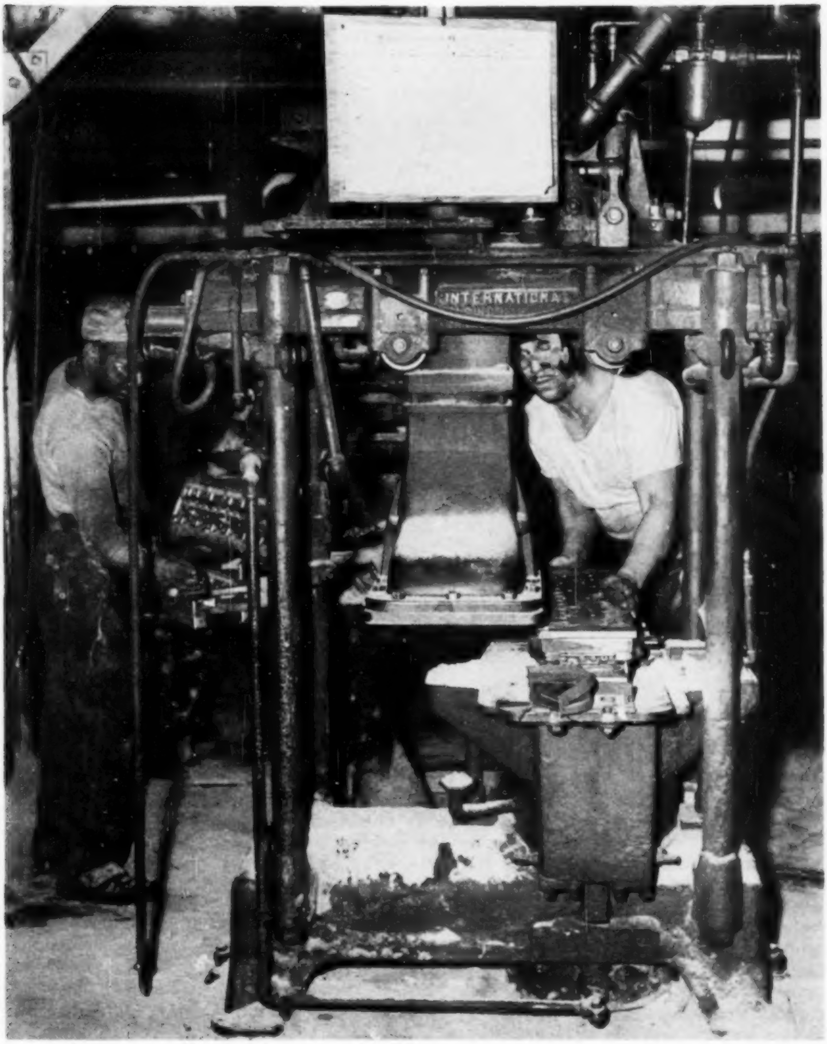
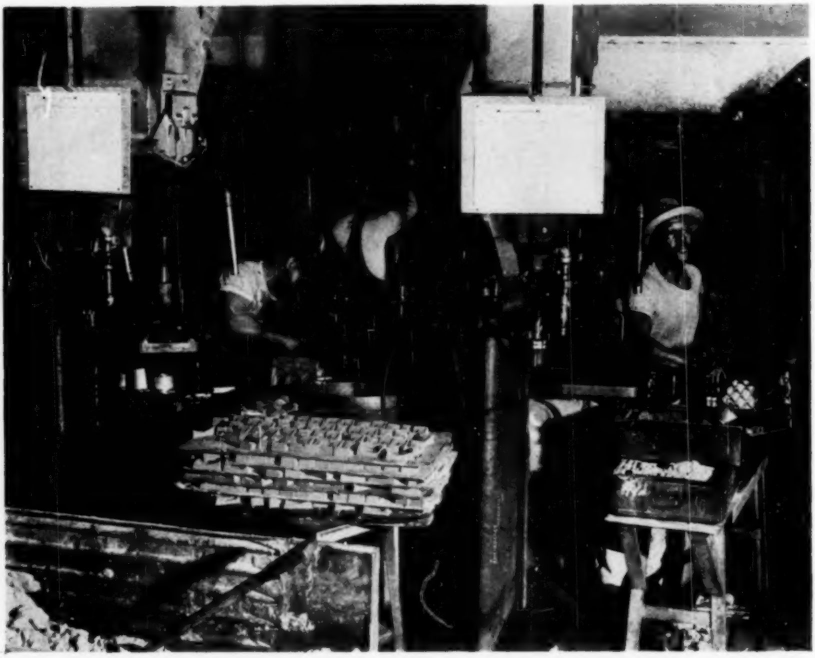


CHART SHOWING THE MOLDERS PERCENT
OF EFFICIENCY IN MAKING MOLDS



We can conclude that, although there is no basic difference between Quality Control in the foundry and other industries, we do have an inherent lack of control that has been built into Foundry Practice. This lack of control cannot be eliminated by setting a tool. There is no meter on our cupola that tells us our analysis. We have to make functional changes, find and devise new methods of control. Statistical Quality Control is the tool that can help us. It has already helped us, but with all the applications that we have made we realize that we have only scratched the surface.

VENDOR QUALITY LEVEL CERTIFICATION

Robert M. Currie
Ford Motor Company

My subject, Vendor Quality Level Certification, is one which is of increasingly vital interest both to suppliers and consumers of goods for production. None of us would be here today if there were not a great general livening of Industry's concern for the use of more adequate ways to build Quality into its products. What has happened to bring this about? Why is there such current emphasis on the "techniques" for Quality Control?

Over the past twenty or thirty years there has been a gradual but most certain drift toward the design of increasingly complicated products to meet what were originally quite uncomplicated basic needs. I don't care if it's alarm clocks or kitchen ranges, the manufacturer of the end product rightly feels that he must be competitive; therefore, he must often furnish the public much more comfort and utility in these products than is basically needed to tell the time or cook the potatoes. If he doesn't, the competition takes his shirt. That is America. Coupled with a peerless system for creating a public desire for better things, it's one of the main reasons why we have developed the World's greatest Production Machine. But with this most desirable advancement in functional design, we fall heir to many new and very tough problems.

What has your product and mine become, with these years of improvement behind it? It has become a most complex thing, capable of providing pleasure and service beyond the fondest dreams of 25 years ago. It is still only able to do its basic job, but in doing it the modern way it is susceptible to a variety of Quality ailments altogether unheard of in the past. For example, there are ten light bulbs in the dash of a fully equipped 1952 Ford Custom automobile. Each of these ten bulbs provides separate opportunity for defectiveness in the finished product, regardless of how exacting the inspections in the supplier's manufacturing plant or our assembly plant may be.

And the public has changed right along with the times too. It knows what it wants. If we do not pay constant attention it will go to a competitor to get it. What does it want——? absolute, utter, unqualified perfection, as measured by every known competitive standard. This means perfection in the design, itself. But it also means perfect faithfulness on the part of the manufacturer in fully reproducing the intention of the design in each and every product going out his door.

This seems to me to be the framework into which Quality Control has been gradually introduced. Now Vendor Quality Level Certification moves into prominence as another of the new tools in the field of Quality Control for economically obtaining end product quality. It fills a long felt though uncrystallized need which has pressed equally upon the suppliers and consumers of production parts and materials much too long.

In our business — and there are many in this audience who are in similar situations — the quality of the end product depends to a very great extent on the performance of hundreds, even thousands, of suppliers. If they do poorly, Qualitywise, then there is some likelihood that even our best inspection efforts will fail to prevent some defectiveness in the field. Recognizing this, we must employ the soundest means at our command to reduce field defectiveness to the lowest possible level, short

indeed of sheer perfection. To this end, Quality Level Certification is, in a sense, the establishing of a partnership between the Quality program of a supplier and that of a consumer.

I want to talk about Certification in a general way for a very few moments. Then I'm going to show you a strip film which describes the mechanics of Certification as we have developed it and are using it at Ford.

The Quality of purchased parts has always been a particular source of dissension and dissatisfaction between suppliers and consumers. All of us know that differences are only ironed out when both parties to the difference finally sit down and establish understanding. This means that my point of view must be reconciled on some common basis with your point of view if we are ever — for our common good — to be agreed. Speaking specifically of Quality, we cannot fully understand one another as long as we permit the measurement of Quality to be subject, as it all too often is, to the "whims" of our respective inspection organizations.

"Black" to me, as a consumer, must be "black" to you, as a supplier. If you see it "grey" or I later start calling it "white," we are surely and inevitably headed for trouble.

It was for reasons of this kind that Ford became interested in developing Certifications with progressive suppliers. Here, in Certification, is a tool which insures that you and I will be talking in precisely the same terms when we talk about the Quality of the part you supply.

In brief, the Quality Level Certification Agreement is an attachment to the purchase contract. In it the vendor proposes to give simple, continuous, documented assurance that each of his shipments meets a mutually established and reasonable Quality Level, with respect to certain important characteristics. As you will see it differentiates between the important and the unimportant. It brings mutual emphasis to the particular dimensions and other features of a part which most directly bear on the Quality of that part in ultimate use. It sets forth in clear detail what this part must be like, in the main, if we are both to call it acceptable. It establishes the amount of defectiveness which, on the average, we shall both consider passable -- and to some industrial people, certainly not to my audience, this a most revolutionary step toward realism. It describes a statistically sound sampling system for measuring the conformance of a lot of material to this mutually established Acceptable Quality Level. And finally, by all these means, it welds your Quality effort inseparably to mine. Our Quality goals as supplier and consumer are identical. Surely it is right that they should be served in a really cooperative way to the best of our combined abilities!

You will observe in the film that Certification is positive, and it is sensible, and it is not complicated. I think this requires particular emphasis. We dare not to offer for general use a tool which scares most people off. At this stage in Industry's expanding acceptance of scientific methods for Quality Control, it would be most foolhardy to go very far beyond the technical scope of the majority of those for whom the very idea is developed. These are not laboratory tools that we must deal with. They are shop tools, simple, readily grasped, and generally applicable. If they are otherwise, they must remain statistical curiosities until there is a sufficient broadening of general knowledge in Industry to permit their full appreciation.

Our approach to Certification has been deliberately tailored with this in mind. Without apology we ask you to remember that the keynote is "understanding," not "statistics." The latter are, of course, introduced as a significant part of the technique, but in the simplest way we could conceive.

In a relatively short space of time Ford has accepted Vendor Quality Certification on more than 170 separate parts. Each has required some initial effort from both the supplier and ourselves. But may I emphasize that it is only the kind of effort that should in any event have been expended if we were ever by this means or by any other to understand one another fully in Quality matters.

Now, here is the film. It was designed to acquaint all of our shop supervisors, production, maintenance, Quality Control and all the others, with the fundamentals. Since our Plants perform in the dual role of both consumer and supplier, you will understand why this training effort is taken.

For the next 25 minutes you will be addressed as one of the 5300 Ford supervisors in the line organization attending his weekly Personnel Development meeting. The pamphlet to which the film refers, at the end, is available to you at the Ford exhibit here in the building. It includes all of the principles, the sampling tables, and some other details which we do not attempt to cover in the film.

Sound - Strip Film - "Quality Level Certification"

Well Gentlemen, that's the story as we see it at Ford. We do not by any means claim that this is the only way to set up a Quality Certification. As we gain added experience, it is quite possible that the program will be modified in some of its details. We will not, however, change the emphases you have just reviewed with us: Cooperation, understanding, and realism.

Quality has substance. We all know that it can be measured and it can be controlled. The public with every purchase of shoe laces or of automobiles expects without any question to buy Quality. It is up to you and me to see that our products perform in every respect as they were designed to perform and as they were purchased to perform. The extent to which Certification will contribute to this end must, like all good things, be governed only by the effort that people like you and I care to devote to it.

I challenge you to join where you can and as you can in what surely shall constitute a major advancement in the science and practice of Quality Control —— Vendor Quality Level Certification.

ENGINEERING THE INSPECTION OF INDUSTRIAL PROCESSES

Nelson G. Meagley
Willys-Overland Motors Inc.

Our use of the term engineering to describe a technical endeavor should indicate a very high development of the art. Definite conditions should be fulfilled. The purpose of this paper is to examine the basic requirements for engineering and to evaluate the present development of quality control in accordance with these terms. The requirements for engineering in any field are considered to be as listed below.

1. Knowledge of the field should be so well understood that the relationship of things can be expressed mathematically. We should possess powers of manipulation such that results can be predicted within definite limits.

2. The scope of the field should be broad enough to require a separate branch of engineering assigned to it, rather than it to function as a department of some existing branch.

3. There must be a literature of technical books and magazine articles and there must be agreement among recognized authorities on the basic principles of the field. The subject should be included in the curriculum of engineering colleges and there should be a professional organization devoted to its activity.

4. There must be liaison between this particular branch of engineering and the rest of the profession, and these other fields must accept its authority in the specified subjects and delegate responsibility for decisions.

This paper deals principally with the engineering of the inspection of industrial processes in terms of the first item only of the above listing.

1. CLASSIFICATION OF QUALITY CHARACTERISTICS

The first requirement for engineering the quality from an industrial process is to have a clear definition of the thing we are attempting to engineer. The different quality characteristics of the part have different degrees of importance. Some types are critical and the failure of the manufacturing process to hold every piece within the specification limits could cause failure of the assembly or endanger those using it. Other characteristics can be classified as major and relate to the important functional dimensions where the design can tolerate a small percentage of the production to slightly exceed the specified tolerances, without significant risk of injury to the assembly. The balance of the quality characteristics are minor in importance and relate to the size, shape or other minor dimensions. Good manufacturing practice require that these be held although rather wide departure from specified tolerance will not seriously effect the use or value of the part.

We have always proceeded in our design, tooling and inspection with the knowledge that there was a difference in importance of the various quality characteristics. We were forced to do this to determine locating points in manufacture and to determine a plan for examining the work. These differences have not usually been defined and listed, however, and there often has been confusion between the designer, the manufacturer and the inspector as to the correctness of their own independent evaluation.

The first requirement for engineering the quality from an industrial process is to have full agreement of all responsible parties to a classification of the quality characteristics of the part.

2. PROCESS CAPABILITY STUDIES

The second requirement is to determine the capability of the processes to hold the tolerances specified; and from this to judge the adequacy of the facilities to produce the part.

Accurate methods for the measurement of process capability have been developed in recent years, principally through statistical techniques of studying the variability of work produced. The average differences in size between consecutive pieces enable us to determine the limits within which 95% or 99.7%, or 68%, or any other stated percentage of the work can be held.

There is a danger, however, that we oversimplify the technique or overestimate our ability to predict the capability of the process. We must clearly understand the statistical principles we are using and the nature of the operation we are measuring.

We must know something about the principle causes for the variability. Some of these are almost completely operator controled and result from skills and personality traits. We cannot expect to exactly duplicate results between different operators. Other operations have tool wear as the principle cause for variability and the economics of tool change costs becomes the governing factor in tolerance. Reamers, forging dies, and some boring operations are examples.

The process capability estimate is based upon the assumption that the tools are set to produce the most pieces in the middle of the specification. Setting tools at this point is sometimes very difficult due to the variability in pieces used to check the tool setting. An allowance for tool setting must be provided in addition to the natural tolerance of the machine tool.

The process capability must be considered as a whole going back through primary operations to establish locating points upon which the critical or major quality characteristics are finished as well as heat treatment or other material variables. Operations producing five major dimensions on a connecting rod required additional process capability studies on 12 primary operations. The capability of the processes for tolerance on spring clips could not be estimated until variability of the heat treat furnaces were measured.

Through the use of these techniques it is possible to establish tolerance requirements of a process with an accuracy not previously obtainable although it requires considerable knowledge of the operations, generally only obtainable by close collaboration between tooling and the Quality Control functions.

3. REVIEW OF TOLERANCES

We have secured agreement among all concerned as to a classification of quality characteristics, and we have determined the tolerance spread required for the processes. The engineering concept of quality control requires that the specified tolerances be wider than the capability of the process. The third point is then to review the tolerances of the specifi-

cation. If the specification is narrower than the process capability, we must decide between one of two choices, either to change the tolerances or to change the process.

If the tolerances as specified are necessary for the proper functioning of the design, then we must change the process, since we know a considerable percentage of out-of-tolerance work will be produced. We can be quite sure that a major change will be required if the capability study has been properly made. One major change possible is to include a 100% inspection operation as a part of the process, to find the defective pieces we know are being produced.

The only other alternative is to accept work knowing that a significant percentage is outside of tolerance. We have stated that the design cannot tolerate this condition so that we must therefore, avoid accepting this alternative.

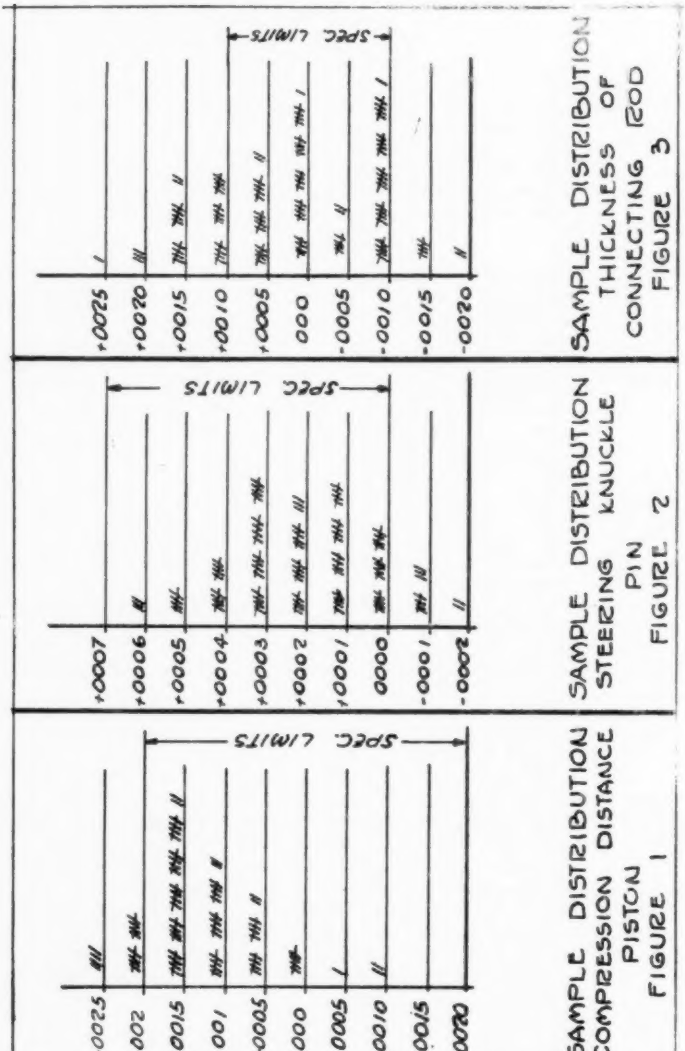
The follow through of the tolerance revision program requires the quality control function to be well integrated into the organization. The designer must understand that a tolerance increase will not result in still greater variability of the work. Failure to grant the increase should automatically initiate a retooling program to provide adequate facilities, and additional inspection time should be budgeted for 100% sorting until these new facilities are provided.

4. SETTING ACCEPTABLE QUALITY LEVELS

The assurance that the process can hold the tolerance does not give assurance that the process will hold the tolerance. There must be a factor of safety to protect the design against the risk that an occasional piece will slightly exceed tolerance limits. These risk factors are similar to the factors of safety used in strength of materials and there should be similar working rules for applying them. We must be able to designate an acceptable quality level (A.Q.L.) stating the percentage of out-of-tolerance pieces we are willing to take, and basing our judgment upon risk considerations of the design. Let us examine some of the working rules we must consider.

A. There is a statistical relationship between the percentage of defective pieces and the amount that the worst ones will exceed the tolerances. For example, Figure 1 shows a typical condition found in inspecting purchased materials. This is a frequency distribution of the dimensional variation observed when measuring a sample of 100 pistons for the distance between the piston pin and the top face. We observe that four pieces or 4 percent are outside of the tolerance. Note however, the relationship between the 4 percent and the extent of the worst condition, or one half of a thousands in a tolerance of .004. Figure 2 shows a similar frequency distribution taken on a ground pin from a steering knuckle. Ten percent of the sample is outside the specification. The worst condition is .0002 in a .0007 tolerance, all being on one side.

Figure 3 shows a frequency distribution of 100 pieces from measuring the thickness of connecting rods. Here we find 23 percent of the samples outside of specification range of .002. The worst pieces are .0015 above the high limit and .001 below the low



SAMPLE DISTRIBUTION
COMPRESSION DISTANCE
PISTON
FIGURE 1

SAMPLE DISTRIBUTION
STEERING KNUCKLE
PIN
FIGURE 2

SAMPLE DISTRIBUTION
THICKNESS OF
CONNECTING ROD
FIGURE 3

Again note that there is a relationship between the quality level or the percentage of out-of-tolerance work, and the extent of the worst pieces. Estimates of these relationships can be expressed by mathematical equations.

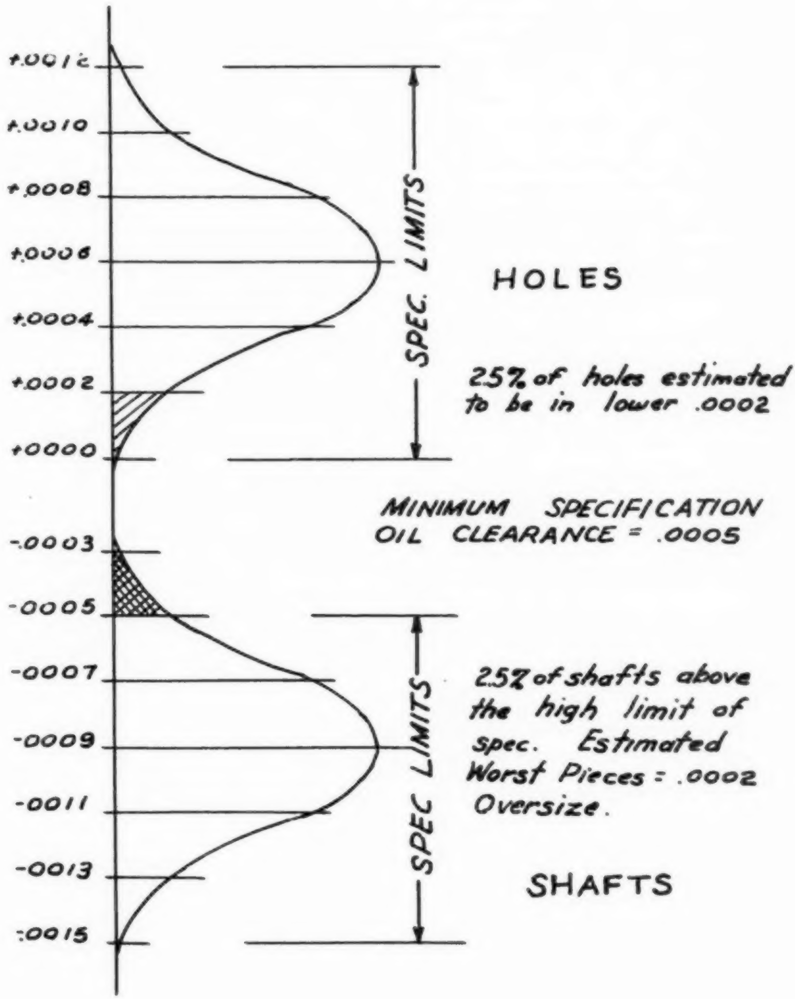


FIGURE 4
TOLERANCE STACK UP ON HOLE-OIL CLEARANCE & SHAFT

B. Quality level of assemblies will be better than the quality level of one of the component parts. Let us suppose for example, that we have two parts, a shaft and a hole, and that these are to be assembled in large numbers. Let us suppose that the hole sizes are evenly distributed about the center of the tolerances and that the full speed of the tolerance is being used. We will have a condition somewhat similar to Figure 4.

We can estimate the percentage of pieces at various segments of the specification. For example if the specification range is .0012 we might expect to find 2.5% of the pieces in the bottom .0002 of the specification. Let us now suppose we are going to assemble these holes with shafts having a quality level of 2.5% defective all on the high side. The tolerance of the shaft is .001 so that we estimate the extent of out-of-tolerance in the worst pieces to be .0002.

The effect of the out-of-tolerance condition will be to reduce the oil clearance allowance below the specified minimum of .0005 in some of the assemblies. This will only occur when one of the large shafts happens to be assembled with one of the holes in the bottom .0002 of the specification. We have already shown 2.5% of the holes are in the range. The probability therefore, that the use of these large shafts will cause assemblies with below specification minimum oil clearance is .025 x .025 or .0006 - that is, 6 in 10,000 and there will still be .0003 oil clearance in the worst assemblies. The quality level of the shafts is 2.5% defective while the quality level of the assemblies is 0.06% defective.

C. Assembly operations often are self-policing and reduce the risk of bad assemblies from bad parts. The shaft illustrated above cannot be assembled if it exceeds the diameter of the hole. If the shaft is far undersized it may not hold oil pressure. A large part of our processing is of this type. If a forge shop were to ship a lot of steering knuckles having a quality level of ½ of one percent cracks, (0.5% defective) it would be very serious. The danger is reduced somewhat however, by dozens of people handling these forgings in subsequent machining and assembly operations.

The stresses on the part during machining are apt to be higher than will ever occur in use so that either breakage may occur or the part will have passed a 100% stress test. Also, all the people handling the knuckle recognize the danger of using a cracked steering part so that the shipment passes through many 100% inspections after it leaves the forge shop. The risk that a lot of forgings at 0.5 defective for cracks would cause field failures is quite low.

D. Measuring the quality level of material now being used without resulting assembly problems or field failures can be often used to estimate the risk of using future shipments at stated acceptable

quality levels. Anyone who has measured the quality of purchased material, allowing nothing beyond the gages, is certain to be impressed with the commercial practices for holding specified tolerances. A small percentage of the work will, in many of the examinations slightly exceed tolerances. Experience has shown this material to be satisfactory.

There are additional risk considerations influencing factors of safety of tolerance and the effects of some of them can be expressed mathematically. The important consideration is that we must recognize the principle of an acceptable quality level (on all except critical quality characteristics) permitting a small percentage of the pieces to slightly exceed the specification limits. We must state this as a definite A.Q.L., and the design must make allowances for it, so that the assembly is not caused to be defective.

5. GAGES

The fifth requirement for Engineering the Inspection of Industrial Processes is the selection of gages and establishing gaging technique.

Gages should tell us two things; first, does the work conform to the specification, and second, does the process need correction and by how much. We must analyze the requirements of the design and tools relative to the critical, major and minor quality characteristics, and select the type of gages required to provide the needed information.

Gages can be classified into two broad types, attribute gages and variable gages. These names state the kind of information the gage gives about the work.

Attribute gages determine that the part does or does not conform to the specification. Examples are snap gages, rings, color chips, chemical spot test, etc. These gages are usually low priced and take very little time or skill to use. They have been of great value in streamlining the inspection of materials. They do not, however, tell us the extent of an out-of-tolerance condition or how close acceptable work is to the danger point. We need this information to determine when the process should be adjusted.

Variable type gages provide this information. Examples are micrometers, indicating snap gages, dial indicators, tensile machines, air gages, weight scales, torque wrenches and comparators of many kinds. Gages have been greatly improved in recent years so that we now have variable gaging divices for most types of operations. Statistical techniques have been developed so that the full meaning of the variation of size can be revealed. A small sample, when given in variable measurements can tell us when to adjust and when not to adjust. We can establish limits of chance variation and assignable causes for variation. A whole body of techniques have been developed for this purpose, such as the XR charts, the Lot Plot, tool setting tables and many more.

A necessary part of the gage phase of inspection engineering is to determine allowances in tolerance that must be provided for variability in reading the gages, and to establish reliable methods to determine the extent of this variability.

There are of course, two types of variability causing a difference in gaged size of the pieces, here called σ_s . There is the variation from piece to piece, here called σ_w. There is also the variation of gaging on the same piece, here called σ_g . We can express this relationship mathematically as

1. $\sigma_s = \sqrt{\sigma_w + \sigma_g}$.

2. $\sigma_g = \sqrt{\sigma_s - \sigma_w}$

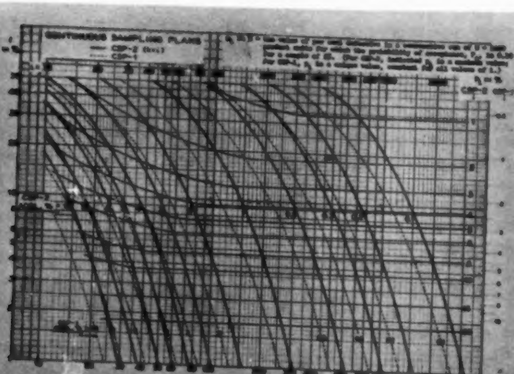
From equation 1 it is apparent that the total tolerance that must be allowed for the process includes the variability of the process itself plus the variability of the gages which are used for the routine control of it. The extent of the variability of gage reading must be and can be measured by process capability studies as in the machine tool itself taking repetitive readings on masters, at different times and by different people.

6. INSPECTION PLANS

The quality engineering of the process up to this stage has classified the quality characteristics as to critical, major or minor. The capabilities of the tools to hold tolerances has been measured and we have either revised the tolerances or replaced the tools. Quality levels have been set showing the maximum out-of-tolerance condition which will be permissable. Finally, we have provided the operation with the type of gages necessary to properly inspect the work and we have separated the variability of gaging from the variability of the work being gaged. All of this has been done with an accuracy adequate to express our results in mathematical term such that our conclusions have a definite meaning, permitting no misunderstanding between the designer, the manufacturer and the inspector together with the sales department of vendors supplying parts to the assembly. Management at all levels has accepted the values as being adequate for the proper function of the design and within commercial practices for the economics of manufacturing.

We are now ready to establish inspection plans to give assurance that the work is being produced in accordance with the acceptable quality levels.

The nearest approach to a fully engineered system are the continuous sampling plans developed by Dodge and his associates at the Bell Telephone Laboratories, one of which is illustrated in Figure 5 and 6. We begin by a selection of an Average Outgoing Quality Limit and a desired percentage inspection. For example we might determine that an A.O.Q.L. of 2 percent would be acceptable and that we desire to inspect 10% of the work. The plan provides a definite sequence of inspection procedure as shown in Figure 6.



Curves for Determining Values of f and i for a Given Value of AOQL.
To find intermediate or larger values of i for a given f, compute from
i_1/i_2 = $(AOQL)_2/(AOQL)_1$, approximately.

FIGURE 5

Willys-Overland Motors, Inc. Date JANUARY 4, 1950

CONTINUOUS SAMPLING PLAN

Part Name CYLINDER HEAD - 6-CYL. Part Number ALL

Quality Characteristics Inspected

CHIPS REMAINING IN CORED SECTIONS OF CYLINDER HEADS AFTER WASHING.

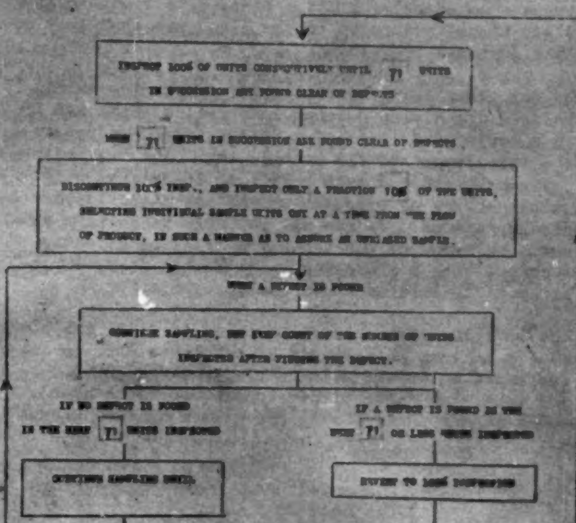


FIGURE 6

A.O.Q.L. 2.0%
Pt Max. 3.7%
f % 10.0%
i 71
k 71

APPROVED BY: JOHN DOE
Quality Control Department

We continue our spot check until we find a defect. When this occurs we continue spot checking but keep count of the number of pieces inspected. If we do not find another defect in the next 160 pieces inspected we stop counting. If we do find a defect in the next 160 pieces sampled, we then discontinue sampling and inspect 100% until we have found 160 consecutive pieces free of the defect. Sampling is then started again and we continue sampling until we again find a defect.

This inspection plan will give us an average outgoing quality limit of 2% and there is a risk of 10% that a lot of 1000 consecutive pieces having 3.8% defectives will pass through the system (called the P_t or Lot Tolerance Fraction Defective) as read from the right side of the chart.

If we find that the quality level of the process continually throws us into 100% inspection, we will increase the percentage of the spot check whereas very infrequent 100% inspection will permit us to reduce the percentage in the spot check, always keeping an eye on the column at the right, for the possibility of a single bad lot passing through the system. If this percentage is too high or too low we will also compensate our percentage accordingly.

These continuous sampling plans, and there are several modifications of them, permit us to give detailed inspection instructions so as to meet specified quality levels at stated risks. The plans are unfortunately still limited to attribute sampling, although work is in progress on adopting similar systems to variable inspection. An additional criticism of the plans are that they require a flexible inspection system.

Sampling plans for practically every type of inspection problem have been developed for giving maximum information about the operation with a minimum of inspection effort. Average range sampling give a measurement of the average size plus the uniformity of size. P charts and C charts permit us to determine if fluctuations about normal or expected values has significance beyond chance considerations. We are not yet able to quickly express the results in terms of lot tolerance fraction defective but we can determine when a process should be shut down, or investigated for an assignable cause of quality variation.

In addition, we have acceptance sampling plans in which the risks of passings stated maximum percentages of defective work is calculated and expressed on an operating characteristic curve. These plans are in a high state of development so as to give quality assurance at any desired risk and with a minimum amount of inspection.

CONCLUSION

In theory at least, we are able to engineer the inspection of an industrial process so as to have a precise statement of our meaning of quality, classifying the characteristics of the part in terms understandable to all parties. We at least approach the art of accurately stating the quality needs of the design in terms of maximum permissable percentages of pieces outside the tolerances, and we are able to inspect the work from the process so as to give a calculated risk that the material meets the requirement. To this extent we fulfill the requirements of engineering.

We have a growing literature which includes hundreds of magazine articles and dozens of books. Quality Control courses are included in the curriculum of over a hundred colleges and some of them are giving degrees of a B.S. in statistics with a minor in engineering. The American Society of Quality Control has received recognition on a professional status in many ways including it's joint participation with the A.S.T.M. and affiliation with the American Association for the Advancement of Science.

The organization of quality control, according to the responsibilities listed above, with authority and an area of operation delegated to it is a new development in industry. It is accepted in widely different degrees by different industrial undertakings.

A sequence of steps for engineering an industrial process has been listed. These are not the only order for the steps or even the best sequence. In practice where we are converting an old process from conventional inspection, there is much to justify starting at the end of the procedure and working backward.

It is not the purpose of this paper to draw the conclusion that the art of quality control has developed into a part of the engineering profession, but only to examine the present state of that art in terms of an engineering approach to the inspection function; and to point out some observations regarding the present state of quality control development.

QUALITY CONTROL TECHNIQUES IN THE AIRCRAFT INDUSTRY

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An Aircraft Technical Committee of the American Society for Quality Control was formed in 1950 and held its first meeting at the Fifth National Convention in Cleveland last year. A program was formulated at that meeting and the desirability of a number of surveys was agreed upon. One of the surveys conducted by this Committee was "Inspection Organizational Structures in the Aircraft Industry". In making this survey the Aircraft Technical Committee membership of the ASQC was canvassed, together with a comprehensive cross section of the manufacturers in the airframe, engine and propeller, and the accessory and equipment branches of the industry.

A detailed report of the survey results has been prepared and distributed to all respondents to the survey. The survey disclosed that the individual manufacturer's inspection provisions followed somewhat similiar patterns as to function, place in the company organization, and responsibility for the quality of the end product. However, one very interesting fact was strikingly evident. Twenty-one point three percent of the companies surveyed titled their functions as "Inspection" while 78.7% used the words "Quality Control" in the name of the department responsible for the acceptability of the items manufactured by those companies. The significance of the swing to a Quality Control philosophy of operation is one important observation which should be drawn from the results of this industry survey.

For years the aircraft industry has employed the 100% inspection procedure to the problem of detection and correction of defectives in the finished product. Recognizing the inability of 100% inspection to cull out all defectives, the industry has frequently resorted to repetitive inspections, sometimes amounting to 200% or 300% inspection. Gradually, over the years, control functions have become added responsibilities of the Inspection Department. It is now generally recognized that the present day composite function is actually one of Quality Control, of which Inspection is a part.

The dictionary defines "inspect" as "to examine closely and critically, as to find possible errors". Inspection has been described as a post mortem, separation operation wherein every effort is made to sort the good from the bad. Obviously such separation is very necessary in the aircraft industry when the importance is considered from a safety point of view only. Quality of the product is tremendously more important to the pilot who may experience an in-flight equipment operational malfunction or a structural failure than it is to the housewife whose electric toaster may fail to toast. In fact, when considered in this light, the quality of the product might well be said to have an entirely different meaning to the pilot than it does to the housewife.

Returning to the dictionary we discover that the noun "quality" is not truly definitive within itself, being described broadly as "that which distinguishes one person or thing from others - degree of excellence". In other words "quality" may mean all things to all people. It is preferable to believe that, for control purposes, "quality" means possessing the specified attributes or in complete accordance with the requirements.

Webster defines "control" as "to restrain, govern, direct, command, influence".

Therefore "Inspection" and Quality Control" are not synonyms but have significantly different meanings. "Inspection" is a sorting operation, conducted after significant amounts of material, machine time and man hours have been expended. "Quality Control" is, in effect, a tool which restrains, governs, and directs the three M's, Material, Machines, and Men, of the manufacturing process to insure that more acceptable work is produced in less time at a lower cost. Quality Control is a work-in-process control as compared with the end-product examination control practised by Inspection.

Of necessity an inspection of the end product is required to evaluate the effectiveness of the process controls exercised on any operation. Such inspection will also serve to point out the necessity for additional, tightened or relaxed process controls. Reasonably satisfactory Inspection controls can be exercised without any Quality Control existant. Such controls, however, are expensive, time consuming, and wasteful of material, machine time and man hours by reason of the fact that these controls are post mortem operations. The individual units, whether they be accepted or rejected, have the same manufacturing costs invested in them. The rejected items, by reason of special handling, rework, or repair, will invariably cost more than the acceptable items. Quality Control, employing work-in-process controls, cannot operate efficiently without the check and balance of a good inspection system to advise the extent and degree of the necessary process controls.

With this understanding of the basic fundamental differences between Inspection and Quality Control operations it becomes quite clear that the aircraft industry has slowly but surely been moving away from a reliance upon product inspection functions only. The controls in use today are largely process controls balanced by an inspection check and surveillance. As shown by the industry survey, 78.7% of the companies now recognize this fact and have altered department titles and organized departmental responsibilities and functions to obtain the best benefits from the practise of process control.

The aircraft industry generally accomplishes process control by close observation and careful control of the principal variables, the three M's, Material, Machines, and Men. Careful study and analysis will disclose the fact that any variable of any process will fall within the scope of one of the M's. If we control the three M's, we control all the variables. This, of course, sounds like wishful thinking. How to do this is the question immediately raised. Complete, never-fail control of materials, machines, and men has doubtlessly never been accomplished. However, much can be done. To illustrate some typical quality control techniques employed in the aircraft industry, certain procedures used at the McDonnell Aircraft Corporation will be outlined.

- MATERIAL -

Believing that a sound foundation is necessary for any structure, the control of raw materials coming into the manufacturing operation is given first attention. MATERIAL control at McDonnell Aircraft begins before the purchase orders are placed with the vendors. A Section of the Quality Control Department reviews each purchase order to verify that all quality requirements are stated thereon. All Purchase Orders for raw and semi-

finished materials, such as castings and forgings, in addition to specifying compliance with applicable government specifications, request evidence of such compliance in the form of actual test reports from approved laboratories. Test bars representative of each heat are requested on all casting orders.

All raw material is doubtlessly carefully controlled at the originating points and in some cases is actually subjected to government inspection at source. However mistakes do occur in identification, handling, and shipping. Therefore upon receipt at MAC the Receiving Inspection Department forwards the test bars, received with castings, to the Physical and Functional Test Laboratory, a Quality Control activity. Representative samples of aluminum alloy sheet, tube, bar, plate, and extrusion products are carefully checked for alloy determination and material condition. Verification is made of the mill identification which appears on the material. Steels, which often do not bear alloy identification on the material when received, present a somewhat greater problem. A sample, of sufficient size to machine a standard test bar or coupon, is cut from one piece of each heat in each shipment. A one inch wafer is cut from each piece in each heat for a heat treat hardenability check.

All of these test samples are machined, heat-treated and tested in the Physical and Functional Laboratory. Examinations may consist of tension, compression, bend, jominy end quench hardness, shear tests, surface hardness, metallurgical and chemical determinations. Upon receipt of an approved Laboratory report the material, when not mill stenciled, is color coded to identify alloy and material condition, verified by Receiving Inspection and placed in Stores.

In addition to the physical, metallurgical, and chemical tests, all castings and forgings are subjected o fluorescent penetrant, magnetic particle, fluorscopic and/or X-ray examination in the Laboratory. Forged billets and similiar materials are thoroughly examined by ultrasonic testing methods prior to release to Stores. Test reports are forwarded to the requesting agency for all tests conducted. By the exercise of these controls and verifications of material alloy and condition together with investigation of physical properties, metallurgical characteristics, and chemical composition, adequate control is maintained of raw materials going into Stores at McDonnell Aircraft. Although detail checks are not made of each material requisition filled, sufficient Inspection surveillance is conducted to assure that the proper materials are issued for each work order.

- MACHINES -

Having exercised reasonable controls over the incoming raw materials, we next turn our attention to control of the second of the three M's, MACHINES. In a strict interpretation of the word we, at McDonnell Aircraft, literally control only one type of machine at our facility. Those machines are the resistance, or spot, welders. We control those machines by reason of the fact that the Quality Control Department certifies each such machine for every gauge and material combination that machine is permitted to weld. These certifications require Quality Control Process Laboratory investigation and test in accordance with the applicable Government specifications. Such tests include bend, tensile, and X-ray, as well as microscopic examination. The physical and metallurgical properties of the welds are determined and the ability of the equipment to reproduce consistent results is verified prior to each material and gauge certification. Test coupons are fabricated and tested for physical properties of the welds for each individual production set-up. Additional specimens are made and test examinations conducted at thirty minute intervals

during the production run.

Although we literally control only this one type of machine in the factory, we actually exercise a significant degree of control of many other machines by the use of $\bar{X}$ and R Charts and other graphic illustrations of the quality of the work produced by the combination of machines and operators. Careful analysis of this data is necessary, however, to segregate the machine variation information. Machine control charts tend to show variations of material, machine or operator and, unless carefully investigated, and the causes, together with the corrective action taken, are clearly indicated on the control chart, it will be quite impractical to segregate the machine failings from the other variables.

For the purposes of control we view our electro-plating and chemical cleaning baths, together with all our heat-treating installations, as MACHINES. Control of the accuracy of these MACHINES is also vested in the Quality Control Process Laboratory. Each chemical cleaning bath and electro-plating solution is carefully and meticulously analyzed at specific intervals. Such analyses may be on a shift, daily, or once a week basis, depending upon the use, or work load, of the specific bath or solution, and its susceptibility to dilution, drag-out, or contamination. The result of each analysis is plotted on control charts in the Process Control Laboratory. When indicated by these analyses the Laboratory secures the necessary corrective action prior to further production use of the specific process.

Each individual heat treat furnace, or bath, is certified by the Process Control Laboratory prior to approval for production use. These certifications require a temperature survey of each specific furnace to assure temperature stabilization throughout the furnace. Temperature readings are taken at five minute intervals until thermal equilibrium is established. Physical tests are conducted on representative samples of the furnace test load to determine that the desired physical properties of the materials have been attained. Additional specimens are suitably sectioned, polished, and etched to permit metallurgical examination of the micro structure of the material for oxidation, grain size and refinement, decarburization, and other significant metallurgical conditions. After certification resulting from the successful conclusion of these tests, continued periodic re-checks are conducted to assure proper atmosphere control, accuracy of temperature control of the furnace, and of the quenching media.

Additional MACHINE controls are obtained by the careful and exacting inspection conducted in the tool grinding room. Each cutting tool used in the machine shops is meticulously inspected after grinding to insure that the right tool in the right condition is always available to the machine operator. All tools are protected by a hot plastic dip to insure no damage to the tool in handling after inspection.

A similiar assurance is made possible by the Quality Control function known as Precision Tool and Gauge Control. In this operation all precision tools in use in the facility, including personally owned inspection tools such as micrometers, are checked for accuracy at individually specified intervals. Such tools are repaired, re-set, adjusted or scrapped as a result of these checks. Adjustable tools are sealed to prevent unauthorized altering of such adjustments. Each individual tool has its own history card which records its new condition and the results of each re-check until the tool is retired. Re-check intervals vary with

the type of tool. A thread gage is so controlled that a daily re-check is made upon it. A torque wrench is controlled to insure a weekly re-check, while transits are re-examined once each month.

Additional MACHINE controls are obtained by the scrupulous care accorded various inspection equipment. The old adage that a chain is no stronger than its weakest link might well be applied to any inspection operation. One of the weakest links could very well be inaccurate inspection tools. Quality Control, therefore, exercises careful surveillance over the accuracy of not only all precision tools, through the operation of Precision Tool and Gauge Control, but of other larger items of inspection equipment. The Quality Control Physical and Functional Test Laboratory's tension-compression testing equipment is periodically re-calibrated to insure the continued accuracy of each machine. The X-ray and fluoroscopic facilities of this Laboratory are also very carefully controlled. Exhaustive certification tests are conducted prior to placing such equipment in use. Continued periodic re-checks are made to insure that no deterioration of the equipment has occurred with a resultant lowered ability of the installation. Standard penetrameters are used for every X-ray or fluoroscopic examination. These penetrameters serve, in effect, as a reference standard for each individual use of the equipment and are extremely useful in evaluating the accuracy of each exposure.

No known method exists for accurate determination of the actual physical properties of a part other than by means of a destructive test. Obviously such tests cannot be made on each piece. Indentation hardness testing devices, such as the Brinell and Rockwell equipment, are available for use. A definite correlation exists between surface hardness and tensile strength; however, because of certain variables, the accuracy of such correlation cannot generally be considered to be better than plus or minus 10%. This is a statistical approximation based upon the results of literally millions of tests. These hardness testing devices are widely used in the aircraft and other metal working industries to verify proper material condition. Quality Control of these machines is achieved by daily calibration and adjustment of each such machine to verify the accuracy of the readings obtained and to co-ordinate the check block readings of all simiiliar machines.

By these procedures a fair degree of MACHINE controls is maintained at McDonnell Aircraft. The opportunity for, and necessity of, additional and more complete machine controls is a constant challenge to the Quality Control analyst. Much remains to be done in this field.

- MEN -

The last of the three M's, MAN, is the most difficult to control probably because here we must deal with that sometimes mystifying element known as human nature. However, MAN is the variable most susceptible to motivating influences. Such influences can cause variation of effort resulting in unsatisfactory output. Conversely, influences can be exerted which are designed to direct man's variations in the direction of better product. Unfortunately, due to the inherent inconsistencies of human behavior, the direct results of specific influences cannot always be predicted with any reliable degree of accuracy. Many factors influence this variable MAN. Although we are primarily concerned with the favorable influences upon this, the most important of the three M's, we must recognize and understand the possible presence of unfavorable forces before we can evaluate and stimulate those more favorable.

MAN on the average, when considered in the singular, is a well balanced individual with very real emotions and ambitions. He inevitably wants to work at some endeavor from which he derives sincere satisfaction and a sense of accomplishment. He wants to better himself in position, the esteem of his fellow workers, and the community in general. He probably has, as an over-all target, the continued financial improvement of his position to the end that he may provide more and better material things for himself and his family.

Understanding these ambitions and desires of the variable MAN, management can study, select, and place proper and suitable favorable influences at work. These can find expression in many ways. There probably exists no definite pattern suitable for all workers in all industry. Each process must be studied and analyzed relative to the worker before the influences most suitable for that specific operation can be determined.

All of the favorable influences might be summed up to spell MORALE. Morale is a composite of many things, including, but certainly not limited to, a zest for the work, a pride in accomplishment, being a member of the team, saying "our" company, referring to collective effort as "we did so and so". Management can foster these things.

A zest for the work can be practically assured when employment methods, training, and skillful supervision has placed the right man on the right job, and that includes matching the occasional square peg with the square hole.

A pride in accomplishment can be instilled in MAN by making him quality conscious. It is management's recognized responsibility to convince the individual that quality is a prime consideration in the company's product. Not how much product is produced, but how much GOOD product in accordance with the established standard, is the actual production goal of any operation.

Being a member of the team is perhaps a little harder to achieve. Management can speak in terms of "our" company, using the pronoun "we" in all expressions to the worker. Simply styling the approach and language will not get the job done, however. Management must be sincere. The individual must know what he is doing and why he is doing it. He is interested in the significant accomplishments of "his" section, department, and company. He does not think of his effort as only that of a welder, for example, but as a member of a team which, as a unit, produces the company's end product. He can be told by management release of information in the form of performance data relative to his section or department, and bulletins, in-plant broadcasts, or other periodic releases of information and news relative to the company's product. The higher the level of management where such releases originate the more favorable the worker reaction.

A measurable degree of MAN control at McDonnell Aircraft is attained in all manufacturing shop classifications by virtue of the fact that each employee serves a 40 working day probationary period at the beginning of his employment. This provides his supervisor with the opportunity to weigh and evaluate each new workman's ability and application prior to the approval of each individual as a permanent employee.

Certain positive degrees of control are attained over men operating in specified labor categories. As an example, each arc or flame welder employed in airframe production must be certified in accordance with a

specific government directive. These certifications are a responsibility of the Quality Control Process Laboratory. The applicant is required to make several standard welded specimens involving butt plate welds, tee welds, tubular cluster welds, and thick to thin combinations of materials. Each of these specimens is sectioned, polished, etched, and carefully examined under the microscope to determine the soundness of the weldment and the penetration of the weld bead into the parent material. Certain specimens are subjected to bend or tension tests to investigate the properties of the weld joint. Upon successfully passing the certification tests each welder is issued a certificate and a badge which describes the materials he is authorized to weld and the type of welding approved. He is also assigned a welder's stamp which he uses to identify all weldments made by him. At one month intervals thereafter a typical production part fabricated by each welder is withdrawn from production use, sectioned, etched and examined by the Process Control Laboratory to verify the continued satisfactory welding ability of each welder. Data relative to original certification and each month's spot check, together with the next six month re-certification due date, appears on Laboratory control charts for each individual welder. If we could plot every individual's output quality characteristics in this manner on suitable control charts, we could do a much better job of controlling this variable MAN. Unfortunately we don't yet know how to do this.

Each magnetic particle or fluorescent penetrant operator, inspector or supervisor is certified by the Process Control Laboratory. Sufficient examinations, written, oral or by actual physical demonstration, are conducted to determine that the applicant understands the care and use of the equipment; that he can accurately detect and evaluate the indications obtained on a part; or that he can devise and install proper and adequate procedures for new material. The required degree of perfection of these varied skills is dependent upon the requirements of the specific classification in which the applicant seeks certification.

Control of the variable MAN is further enhanced by objective training or instruction for specific operations. As an example, each mechanic who installs explosive rivets has had detailed training for that work. Each mechanic who performs hot dimpling of metal parts is authorized to do so only after extensive training in the "why" and the "how" of that work. Further MAN controls are possible by examination of machine or process $\bar{X}$ and R Charts and similiar control media.

A degree of control of the variable MAN is maintained in the inspection job categories at McDonnell Aircraft by the careful consideration given to each new inspection applicant. Considerable importance is, of course, attached to the applicant's past education and job history. In all cases possible the new inspector is upgraded from some other classification within the company. In addition to past employment and educational history each potential inspector's I.Q. and general knowledge is measured by two standard tests; the Wonderlic Personnel Test and the Morgan Achievement Test in Mathematics. Additional tests are given to determine the applicant's understanding and ability to read blueprints.

After successfully passing these tests the applicant is classified as a trainee inspector. He is given an intensified two week class room training course covering such subjects as Company and Customer Processes and Specifications, Shop Practice, MAC Engineering Manual, AN Standards Manual, MAC Quality Inspection Manual, Inspection Procedures, and the preparation and use of the various Inspection forms and reports. At the

end of this class room training the embryo inspector is given specific on-the-job training for an additional two weeks. During this period he is closely supervised and instructed by a Grade 1 inspector. This latter two week period is also used as a preliminary probationary period during which the Inspection Supervisor to whom the trainee is assigned will determine the acceptability of the trainee as an Inspector. If acceptable he is re-classified to the inspection classification to which he is best adapted as determined by his previous work history, the instructor's evaluation, and the scores obtained in the pre-employment personnel tests.

After re-classification to an Inspector rating the individual is considered to be on probation for 40 working days. During this period his progress and ability is carefully observed and evaluated by his supervisor. If his efforts are satisfactory he is considered a full fledged inspector. If his efforts are not up to standard he is released from the Inspection Department by transfer to his original job classification or elsewhere within the company. He is not released from company employment until every reasonable effort to gainfully employ his talents has been exhausted. In addition to training individuals for specific jobs careful attention is always given to matching the square pegs with the square holes.

MAN controls within the Inspection classifications are continually enhanced by the training opportunities offered the personnel. A refresher course in mathematics and a basic course in Statistical Quality Control are available at all times to all who wish to enroll, plus additional specialized short courses of study which are available from time to time.

This field of MAN controls offers almost unlimited opportunities for the Quality Control analyst. Although some degree of control has been developed and is in use today the necessity for additional controls and refinement of existing controls must be given increasingly more attention.

The Inspection Section of the Quality Control Department at McDonnell Aircraft is, in reality, the verification section of that department. The Inspection Section, through the data obtained in its daily operations, supplies the Quality Control Section with vital information relative to the adequacy of present controls, the necessity for new or additional controls, as well as quantitative knowledge relative to those same three M's, Material, Machines, and Men.

Although the average inspection system in use in the aircraft industry presently makes little use of the various sampling plans for acceptance inspection, trends in that direction are increasingly evident. All receiving inspection departments do use sampling plans for acceptance inspection, usually in accordance with the requirements of MIL-STD-105a or a modification thereof. The larger lot sizes encountered in Receiving Inspection, plus the fact that the supplier has probably subjected his product to some type of inspection, makes this operation particularly adaptable to the statistical acceptance techniques. The adaption of such acceptance sampling methods to bench, line, and assembly operations is not yet widely practised by the airframe manufacturers. Statistical sampling plans are used, however, to evaluate the efficiency of 100% inspection systems.

The McDonnell Inspection Section furnishes, through daily inspection reports, the data from which Quality Control creates A.Q.L., meaning in this case Actual Quality Level, charts for each shop department. These

charts are percent defective charts and graphically depict the actual reject, rework and repair statistics for each department. Such charts are prepared on a cumulative weekly basis and are prominently posted in each shop in addition to routine distribution to the shop supervisors, the factory superintendent, factory manager, and others in management primarily concerned with production at the desired level, of an acceptable quality, at a reasonable cost.

In these days of material shortages, allocation, and controls, equipment procurement delays, and scarcity of qualified trained personnel, all industry must continue to develop and implement more and better Quality Control techniques. Process Control is of primary importance. The tail cannot be allowed to wag the dog as is the case when end-product inspection only is used. Industry generally, and the aircraft industry specifically, has scarcely scratched the surface of control possibilities. Opportunities for additional control development are manifold. Some of us have progressed further than others but the average use of true Quality Control in the aircraft industry can and must be expanded many fold.

CONTROL CHARTS USING MIDRANGES AND MEDIANS

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ABSTRACT

The midrange of a sample or subgroup is half the sum of the largest and smallest. Like the mean and the median it is a central value. It is proposed to construct control charts using ranges and midranges within subgroups and medians of these statistics between subgroups. Under conditions of statistical control, these statistics are somewhat less efficient than those usually employed to estimate the parameters of a parent universe. But it often happens that a set of data comprises, in addition to those observations that represent a common parent universe, some observations that represent disturbances or assignable causes of variation. Under these conditions the method proposed tends to give more useful estimates of the universe parameters. It also tends to be more effective in detecting and locating such disturbances. It involves simpler computations and hence invites analysis of data on the spot, rather than as a separate and later operation.

* * * * *

TABLE I

Factors for Control Charts Using Ranges, Midranges, and Medians

n	A_4	d_4	D_5	D_6
2	2.224	0.954	0	3.865
3	1.137	1.588	0	2.745
4	.828	1.978	0	2.375
5	.679	2.257	0	2.179
6	.590	2.472	0	2.055
7	.530	2.645	0.078	1.967
8	.486	2.791	0.139	1.901
9	.453	2.916	0.187	1.850
10	.427	3.024	0.227	1.809

$\bar{X}'$ = Mean of parent universe
σ' = Standard deviation of parent universe
n = Size of subgroup
R = Range of subgroup = Max. − Min.
M = Midrange of subgroup = (Max. + Min.)/2
$m(R)$ = Median of the ranges
$m(M)$ = Median of the midranges

Estimates: $\bar{X}' = m(M)$
$\sigma' = m(R)/d_4$

3-sigma Limits: Lim $M = m(M) \pm A_4 \cdot m(R)$
Lim $R = D_5 \cdot m(R)$ and $D_6 \cdot m(R)$

The complete paper is being submitted to INDUSTRIAL QUALITY CONTROL for publication.

QUALITY CONTROL OF STEEL MANUFACTURE

Richard H. Ede
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In reviewing previous conference papers on the subject of "Quality Control of Steel Manufacture", it would appear that the subject has been rather thoroughly covered. Many excellent papers have described unique and useful applications of the various tools of quality control, and it would be somewhat of an anticlimax to go over the same ground. It would seem appropriate at this time to make a progress report of new developments, at least new in that they have not appeared in publications on the subject.

One of the simplest and most effective control chart applications was developed on the heat times of a series of open hearth campaigns at one of our plants. In defining a campaign it should be mentioned that the brick work and other materials which are used in the construction of an open hearth furnace are subject to a considerable amount of erosion at the high temperatures used in steel making. It is customary to make heat after heat in a furnace, making such repairs as are needed, to a point where a complete rebuilding job is required. The number of heats made in a furnace from one rebuild to the next is called a campaign.

During the early stages of a campaign, when everything is in good order, the time required to make a heat of steel is relatively short, but during the latter stages, heat times have a tendency to lengthen out. This may be illustrated by a sample control chart on a rather typical campaign before changes in operating practices (Figure 1). The object of the application was to signal the first occurrence of a significant increase in heat time and permit corrective action in order to keep the heat times from lengthening excessively toward the end of a campaign.

A preliminary survey of the characteristics of heat times throughout a campaign indicated that the eleventh to the seventieth heats were most representative of what a furnace was capable of doing. Using this interval as a basis for computations, statistical control limits were computed for each furnace. Evidences of lack of statistical control as well as wide differences in averages between furnaces in the same shop were considered points of action. A special group was assigned to the task of finding the assignable causes. Many significant changes in open hearth facilities and operation resulted in the improved furnace performance shown in Figure 2.

In operation the charts proved effective in indicating the performance of the furnace, especially the condition of the checkers which preheat the air used in the fuel-air mixture for heating scrap, iron and other raw materials charged in the furnace. A program of repairing leaks and other causes of checker inefficiency, along with the introduction of more efficient checker cleaning methods contributed in part to the reduction in heat times, particularly in the latter stages of a campaign.

FIGURE 1

SAMPLE CONTROL CHART ON CAMPAIGN OF HEAT TIMES
OF AN OPEN HEARTH FURNACE
PRIOR TO CHANGES IN FACILITIES AND OPERATING PRACTICES

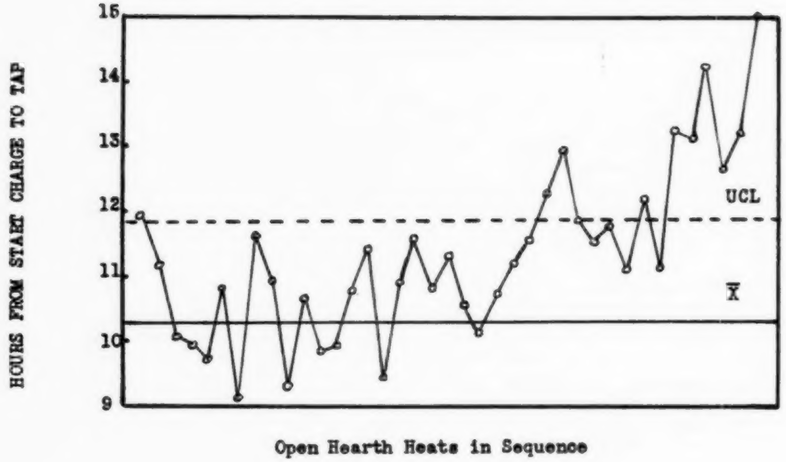
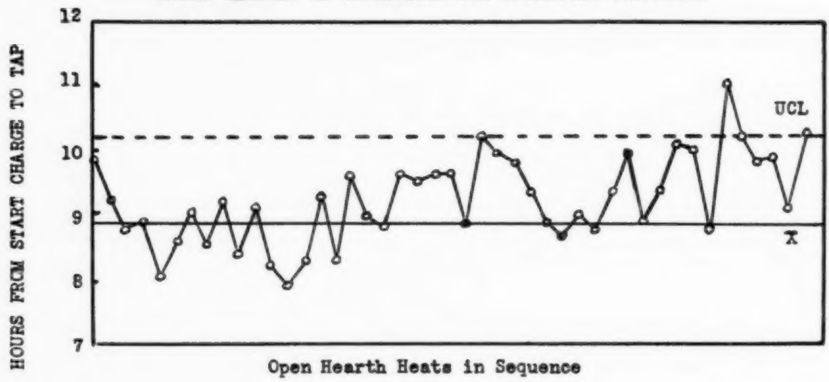


FIGURE 2

CONTROL CHART ON CAMPAIGN OF HEAT TIMES
OF SAME FURNACE FIVE MONTHS
AFTER CHANGES IN FACILITIES AND OPERATING PRACTICES



Another type of chart was developed in connection with efforts to improve the operation of the soaking pits used to reheat ingots to the proper temperature for rolling. The time required to heat a charge of ingots is dependent on the size and number of ingots charged as well as the delivery time which is the time required to transport the charge from the open hearth shop to the soaking pits. With these variables, a standard control chart procedure is not effective.

Before charts could be developed, it was necessary to determine the amount of heating required for various ranges of the three variables in question. This was accomplished by a non-linear multiple correlation study of a considerable amount of data from several of the sharpest or best-heating, soaking pits. The results were set up in table form in which standard heating time aims were listed for (1) each increment of delivery time, (2) the number of ingots in the charge, and (3) the general ingot classification as determined by size and type.

SOAKING PIT HEATING TIME BOGEY

Ingot Size	No. of Ingots in Pit	Transit Time in Hours and Minutes*										
		2:00	2:10	2:20	2:30	2:40	2:50	3:00	3:10	3:20	3:30	3:40
22x40 23x35 26x34	10	2:45	3:04	3:22	3:37	3:48	3:58	4:07	4:15	4:23	4:31	4:38
	11	2:46	3:07	3:25	3:40	3:51	4:01	4:10	4:18	4:26	4:34	4:42
	12	2:48	3:10	3:29	3:44	3:55	4:05	4:14	4:22	4:30	4:38	4:46
	13	2:50	3:13	3:34	3:49	4:01	4:11	4:20	4:28	4:36	4:44	4:52
	14	2:53	3:17	3:38	3:54	4:08	4:19	4:28	4:36	4:44	4:52	5:00
22x50 22x56 22x68	10	2:47	3:11	3:30	3:45	3:56	4:06	4:15	4:23	4:31	4:39	4:46
	11	2:50	3:15	3:35	3:50	4:01	4:11	4:20	4:28	4:36	4:44	4:51
	12	2:53	3:19	3:41	3:57	4:08	4:18	4:27	4:35	4:43	4:51	4:58
	13	2:57	3:23	3:47	4:05	4:17	4:28	4:37	4:45	4:53	5:01	5:08
	14	3:00	3:27	3:53	4:14	4:27	4:40	4:51	4:59	5:07	5:15	5:22

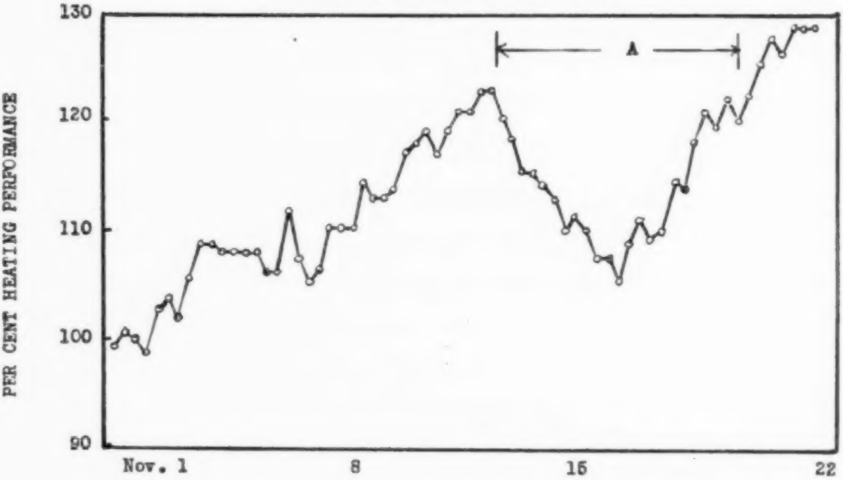
* "Transit Time" is computed for this purpose as the Time from tap to start charging ingots in pit.

Note: The hours and minutes shown in each transit time column is the standard or "Bogey" time required for the given number of ingots of the designated size to reach temperature and be considered as "Ready to Roll".

Heating performance charts for each pit are developed from this table by comparing the actual time required to heat each charge with the standard time listed in the table for the corresponding delivery time, ingot size and number. The performance rating is obtained by dividing the standard heating time by the actual heating time and multiplying the result by 100 to give a percentage figure. These percentages are plotted for each pit on a ten-charge moving average basis to smooth out the charge-to-charge fluctuations. (Figure 3).

FIGURE 3

HEATING PERFORMANCE CHART ON A SOAKING PIT
DURING TRIAL OF AN EXPERIMENTAL BURNER
PROVIDING IMPROVED GAS-AIR MIXTURE



o - Each point indicates a moving average of ten charges.

A - Period of cold weather, low gas pressure and transportation delays.

Such charts enable the operators to make performance comparisons from pit to pit and from time to time much more accurately than has been possible by review of usual daily records. Generally inefficient pits are examined so that they may be brought up to the level of the more efficient pits. Any sudden or gradual declines in pit efficiencies are studied in order that the causes may be found and corrected. These efforts have resulted in a greater tonnage of steel heated with less fuel used per ton.

It is in the field of common, everyday mill and shop problems that the greatest challenge is offered to the metallurgist in the control of quality. A steel manufacturer makes a wide variety of products, each of which requires some difference in processing both as to materials used and methods of handling. It is a common experience for a certain grade of steel, which for months had caused no trouble, to become a major problem over night. A cursory examination of steel making and rolling variables may not reveal important changes in processing, and the problem is presented to the metallurgist to find the cause of poor performance.

To be effective, a method of analysis should be capable of rating the significance of processing factors singly and in combination from a relatively small sample. It should be capable of handling variables and attributes alike, and above all, it should be quick and simple to perform. It has been our experience that the "unweighted means" approach to analysis of variance (1) fits these requirements. Because this approach does not demand equal representation in each sub-group as do most of the other variations of analysis of variance, the scope of possible applications is greatly widened. Another advantage of this approach lies in the assumptions made in classifying the raw data. Many variables in steel processing are observations or estimates and, as such, are subject to a considerable degree of error. To use estimated figures in the same manner as accurate measurements in a precise method, such as multiple correlation, is to be slightly unrealistic. In the small sample stage of a problem, the time, effort and interpretations necessary do not appear to be warranted.

In the interest of simple computations and of stretching a small sample into the largest number of sub-groups, each factor, variable or attribute, is limited to a two-way classification. Variables are either short or long, low or high, et cetera, and attributes, one or the other of two things or two kinds.

With such a division, the classification of each factor can be listed heat by heat opposite its respective scrap percentage figure or other measure of quality (Table 1). This can usually be done directly from regular shop reports which saves the time of making a tabulation of the data. Upon completing the listing, the quality rating figures are re-arranged according to the classifications shown in Table 2. For example, the classes 1, 2, 1 in Table 1 opposite the first scrap figure, indicate that this scrap figure belongs in the third column in Table 2.

When the classification has been completed, the average of each column is obtained along with the number of items in each case. It is at this point that the unweighted means method departs from the standard analysis of variance approach. The averages are treated as if they were individual items, and their mean squares are obtained in the usual manner. Then each mean square is multiplied by the harmonic mean to convert to the original level, and F-ratios are formed. The entire procedure is outlined in "cook book" style in Table 3. An example of this type of solution is shown in Table 4, using the data classified in Table 2.

Results obtained from applications of this method to a wide variety of mill problems have been very gratifying. Many of the sources of trouble have been located in combinations of factors which appear in the interaction classifications of this procedure. Both the detection and interpretation of trouble occurring in such combinations can be accomplished more simply by this procedure than by any other method that we have tried.

Our present plans call for a comprehensive control chart program based on the findings of analyses of individual problems. Once it has been demonstrated that a variable, or combination of variables, is a consistent trouble-maker, it appears practical to maintain the proper level of good quality by means of a statistical control chart. In this manner, the number of useless chart applications is kept to a minimum.

The unweighted means approach to analysis of variance is not designed to take the place of a larger and more formal analysis of a problem. Applications are made at a time when data are limited and any such complete analysis would be out of the question. As a means of "spotting" trouble, it appears to have the knack of getting the most out of the smallest amount of data. Because the term "analysis of variance" has been so closely identified with "designed" experiments, its potential value as a procedure for general analysis purposes has been neglected. Any industry, in which some of the answers to quality problems must be determined from data which are at times of limited accuracy, should find this approach useful.

Reference

(1) G. W. Snedecor, "Statistical Methods", Page 287

UNWEIGHTED MEANS APPROACH TO ANALYSIS OF VARIANCE

For each heat it is noted whether the variables or factors suspected of influencing the amount of scrap produced lie in a low or high range. This is generally determined by estimating the median of each factor and calling all values below the median Class 1, and all values above the median Class 2. Attributes can be arbitrarily classified in the same manner; e.g., a slab mill may be called Class 1 and a blooming mill Class 2 in cases where the same type of product is rolled on both mills. Data from plant reports may thus be quickly classified as in the following example:

Table 1

% Scrap	Factor I	Factor II	Factor III	% Scrap	Factor I	Factor II	Factor III
4	1	2	1	3	1	2	1
0	1	2	2	3	1	2	1
4	2	1	1	0	2	2	2
2	1	1	1	0	1	1	1
1	2	2	2	1	1	1	1
3	2	2	2	10	1	2	1
5	2	2	1	8	2	2	1
2	1	2	2	0	2	1	1
7	2	2	1	5	2	1	2
2	2	2	1	0	1	1	2
3	1	1	2	0	1	1	2
1	1	1	2	3	1	2	2
0	1	1	1	7	2	1	2
7	1	1	2	0	1	2	2
2	2	1	1	0	2	2	1
0	1	2	2	2	2	2	1
9	2	1	2	6	2	2	2
3	2	1	2	2	1	1	1
5	2	2	2	1	1	1	2

Table 2

Per cent scrap figures listed in the eight possible combinations of a 2 x 2 x 2 classification

Factor I	Class 1				Class 2			
Factor II	Class 1		Class 2		Class 1		Class 2	
Factor III	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2
	2	3	4	0	4	9	5	1
	0	1	3	2	2	3	7	3
	0	7	3	0	0	5	2	5
	1	0	10	3		7	8	0
	2	0		0			0	6
		1					2	
Number	5	6	4	5	3	4	6	5
Total	5	12	20	5	6	24	24	15
Average	1	2	5	1	2	6	4	3

No. of individual items = 38   No. of Averages = 8

Sum of individual items = 111   Sum of Averages = 24

Sum of Squares items = 617   Sum of Squares = 96

Table 3

Unweighted Means Method of
Analysis of Variance

Direction for a 2 x 2 x 2 Classification.

Factor I	Class 1				Class 2			
Factor II	Class 1		Class 2		Class 1		Class 2	
Factor III	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2
Averages =	a	b	c	d	e	f	g	h

1. Number of individual items
2. Sum of individual items
3. Sum of squares of individual items
4. Square No. 2 and divide by No. 1
5. Total sum of squares = No. 3 - No. 4
6. No. of averages
7. Sum of averages
8. Sum of squares of averages
9. Square No. 7 and divide by No. 6
10. Total sum of squares = No. 8 - No. 9

Sum of squares for factors:

11. Factor I (a+b+c+d) - (e+f+g+h) sq. difference and divide by 8
12. Factor II (a+b+e+f) - (c+d+g+h) sq. difference and divide by 8
13. Factor III(a+c+e+g) - (b+d+f+h) sq. difference and divide by 8

Sum of squares for 1st order interactions:

14. Factor IxII (a+b+g+h) - (c+d+e+f) sq. difference and divide by 8
15. Factor IxIII (a+c+f+h) - (b+d+e+g) sq. difference and divide by 8
16. Factor IIxIII(a+d+e+h) - (b+c+f+g) sq. difference and divide by 8

Sum of squares for 2nd order interactions:

17. No. 10 - (Nos. 11 + 12 + 13 + 14 + 15 + 16)

To convert sums of squares back to individual level:

18. Multiply Nos. 11 to 17 inclusive by harmonic mean*

$$\text{Harmonic Mean} = \frac{N}{1/Na + 1/Nb + 1/Nc + 1/Nd + 1/Ne + 1/Nf + 1/Ng + 1/Nh}$$

Residual or error sum of squares:

19. No. 5 - (Total of No. 18)

Get mean squares by dividing each sum of squares by its corresponding degrees of freedom. In a 2 x 2 x 2 classification all degrees of freedom will be 1 except for the residual. Degrees of freedom for residual will equal the total number of individual items minus the total number of classes.

Get F ratios and compare with F values from table in Snedecor's "Statistical Methods", Freeman's "Industrial Statistics", etc. F ratio = mean square of factor or interaction divided by mean square of residual.

* Harmonic mean for attached problem $= \dfrac{8}{1/5 + 1/6 + 1/4 + 1/5 + 1/3 + 1/4 + 1/6 + 1/5} =$

$$\frac{8}{.2 + .1667 + .25 + .2 + .3333 + .25 + .1667 + .2} = \frac{8}{1.7667} = 4.5282$$

Table 4

Solution of problem classified in Table 2 according to direction sheet for a 2 x 2 x 2 classification.

For Individual Items		For Average	
1.	$N = 38$	6.	$N = 8$
2.	$\Sigma X = 111$	7.	$\Sigma \bar{X} = 24$
3.	$\Sigma X^2 = 617$	8.	$\Sigma \bar{X}^2 = 96$
4.	$\frac{(\Sigma X)^2}{N} = 324.24$	9.	$\frac{(\Sigma \bar{X})^2}{N} = 72$
5.	Total sum of squares = 292.76	10.	Total sum of squares = 24

	Factor	Class 1	Class 2	Diff.	$(Diff.)^2$	$\frac{(Diff.)^2}{8}$	Harmonic Mean	Sum of Squares	Degrees Freedom	Mean Square	F Ratio	F .05	F .01
11.	I	9	15	6	36	4.5	4.5282	20.38	1	20.38	3.32	4.17	7.56
12.	II	11	13	2	4	.5	4.5282	2.26	1	2.26	.37	4.17	7.56
13.	III	12	12	0	0	0	4.5282	0	1	0	0	4.17	7.56
	1st order Interaction:												
14.	I x II	10	14	4	16	2.0	4.5282	9.06	1	9.06	1.48	4.17	7.56
15.	I x III	15	9	6	36	4.5	4.5282	20.38	1	20.38	3.32	4.17	7.56
16.	II x III	7	17	10	100	12.5	4.5282	56.60	1	56.60	9.22	4.17	7.56
	2nd order Interaction:												
17.	I x II x III 24 - 24 = 0						4.5282	0	1	0	0	4.17	7.56
19.	Residual 292.76 - 108.68 =							184.08	30	6.14			

CONTROLLING THE CONTROL LABORATORIES IN A CHEMICAL FIBER MANUFACTURING PLANT

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INTRODUCTION

"Let's send another sample to the laboratory. This batch can't be as bad as they say it is. Something must be wrong with their analysis." You may never have heard a production foreman say this, but I and a good many others have. It does not give you a comfortable feeling, if you are associated with the laboratory involved. This desire to send another sample to the laboratory stems from two sources. One is lack of confidence in the laboratory's performance. The other is a little more subtle. I think it must be a feeling that if enough samples can be taken and enough undesired results discarded (righteously, because the laboratory is wrong), then eventually a correct (desirable) result can be obtained. It is proposed in this paper to discuss some of the steps which can be taken to help remedy any lack of confidence which might exist. The discussion will apply to control laboratories generally, but the illustrations will be taken from laboratories in a chemical fiber manufacturing plant because I am most familiar with these.

But first, let us review the purpose of a control laboratory. Stripped of all of its trimmings, its chief job is to sample a product, test or analyze it for a quality, and report the results in a form suitable for use by the production department as a basis for making decisions and taking action. Moreover, all of this must be done in a manner which makes the results have validity, the required precision, be in a state of statistical control as far as the laboratories own work is concerned, and be available in time for use.

CONTROL OF ANALYSTS

Analysts need instruction in what they are to do. The kind of instruction they receive has considerable influence on the quality of the results reported by the laboratory. For example, if two analysts are told simply to weigh out 5 grams of a certain reagent to be used in a routine analysis one analyst may very well decide to use a fourth place analytical balance and the other to use a trip balance. In such a case the precision of the test method would likely be different for the two men. Likewise, the precision or even accuracy of a test could be affected by leaving a flask of reacting material in a constant temperature bath different lengths of time depending on the analyst's interpretation of, say, "allow to come to constant temperature in a 25° bath". Again, if instructions say take a sample of five bobbins at random without specifying how randomness is to be achieved, one person is likely to introduce one bias and another person a different bias. Again the validity of the test can be seriously affected by small changes in procedure when one analyst, in teaching another, passes on his own little innovations or short cuts. These and similar considerations lead to the conclusion that, for control, procedures and specifications must be not only written down so that they are not inadvertently changed, but instructions must be very carefully written so that interpretation is easy. We are convinced at our plant that time spent in clarifying instructions and reducing them to writing saves many fold as much time in looking for elusive troubles.

We have developed four formats for different kinds of procedures. All

laboratory manuals are required to conform to the appropriate format. They are shown in figures 1, 2, 3, and 4. The "Sample Summary" is intended to be a guide for the technician in taking a sample. The "Equipment Methods" describe how apparatus such as pipets, balances, and colorimeters are to be used and cared for. The "Preparation Methods" tell how to prepare reagents. And the "Analytical Methods" give directions for making the analysis or test. Most of our analysts are high school graduates. Therefore, in writing methods we try to aim the language at their level, explaining all terms which would not be familiar to them, and taking into consideration their contact with usual laboratory apparatus. We find that this simple style of writing helps chemists, engineers, and foremen as much as it does the technicians. When a procedure is edited the criterion used to judge it is: Could a trained analyst justify an interpretation other than the one intended?

After instruction, analysts must be checked on a continuing schedule to see that they do not deviate from the established procedure. One way to do this is to actually watch them as they do their work, comparing what is seen with the written instructions. This is a necessary thing to do, but, as you know, "the proof of the pudding is in the eating". Therefore the most important thing to check is the result.

To check the results of a test one usually longs for a standard sample which seldom, if ever, is at hand, or for that matter which can rarely be obtained. Take, for example, the testing of yarn for strength. I know of no supply of a standard sample or of how to prepare one. Consider also a yet more difficult situation where a mixture still in the process of reacting must be tested to determine how far the reaction has progressed. This difficulty of not being able to obtain a standard sample can be overcome satisfactorily in a control laboratory by a method to be described.

Suppose that a satisfactory standard sample is available with the quality characteristic of interest known. One could disguise the sample by coding the identification, and submit it to the technician for analysis along with his normal routine samples. Then a comparison of the reported and known values could be made. It is the opinion of those of us in charge of the laboratories at our plant that this is a very poor practice. We never do it. It is poor because we would be deceiving the analyst in that we would be telling him that the sample is one thing when in reality it is another. We want him to play fair with us, so we must play fair with him. Even though you warn the analyst that this may be done from time to time, it still bears a taint of deceitfulness. You cannot avoid the facts that you must trust the analyst, and that you are almost completely at the mercy of his integrity. Since the only way to make a man trustworthy is to trust him, we do just that.

Checking can be put on another basis, and be given a different tone. Tell the analyst that you are going to check his work at odd intervals. Tell him that while you trust in his honesty, checking is necessary because even though he does not want to allow it to happen, he may inadvertently change his technique, or his equipment or reagents may change.

Select a person to be designated as auditor. Have this man run the same test on the same material as the analyst to be checked using the routine samples. The times at which the two runs are made may or may not be the same, depending on the nature of the material involved and convenience. The frequency of checking should be determined by the same considerations as any other sampling scheme.

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FORMAT FOR SAMPLE SUMMARY (Note 1)

Definition

Define the material to be sampled, giving common name as distinguished from plant slang, and locating the material in the stream of production. For example, dull header dope would be defined as follows: The viscous mixture of cellulose acetate, titanium dioxide, acetone, and water, filtered and ready for spinning into dull yarn.

Sampled by

Name, by job title and department, all persons involved in obtaining and transporting samples. Indicate what part in procedure they take.

Sampling Point

Be specific. For example, full cone creel on coning machines.

Sampling Time

Be complete and precise so that frequency of sampling can be inferred without difficulty. For example: 8 to 9 A. M. Monday, Wednesday, and Friday for each of the three systems.

Safety Equipment

State safety equipment needed by sampler. If none, so state.

Container

Name the container into which the sample will be put for transportation to the laboratory (Note 2).

Sampling Procedure

Describe procedures for determining which item to take and how to take it.

Keep sentences short. Begin each with the verb denoting the action to be taken where reasonable. Be complete and precise so that following directions will result in sample being taken in proper manner.

Sample Size

Sample size can be extracted from "Sampling Procedure," but here state concisely its size. For example: 2 to 4 grams; or, one eight gram composite skein from 20 bobbins.

Identification

State how sample is identified and what information is required. For example: Record yarn item name, machine number, doff time and date on paper tag. Place tag in metal can with sample skeins.

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Deliver To

State where and to whom sample is to be delivered.

Analysis Or Test For

	Limits (Note 2)
State all qualities to be measured	State limits

Normal Report

State how and to whom report of results is made.

Out-of-Limits Action

State how and to whom out-of-limits results are reported. State modifications of normal sampling scheme called for, if any.

Recorded

State how permanent record of results is made.

Notes

1. State first material to be sampled followed by qualifying terms. For example, Acetate yarn, spin bobbin.

2. Use notes to describe containers not sufficiently covered by name, or to give directions for making or conditioning same.

3. State whether control or specification limits. If both have been set, exhibit both. If neither have been set, give expected range, that is, the interval within which results are likely to fall, arrived at by a rough estimate. Give limits for variation and average. State number of individuals included in reported results. For example:

Control Limits for Average of Five Bobbins, Duplicate Determinations

132.6 - 149.3

4. Use notes to give explanation, hints or precautions too long to include without detracting from the flow of directions.

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Figure 1. Format for Sample Summary

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FORMAT FOR PREPARATION METHODS

Definition

Define the material to be prepared, giving limits of accuracy required, for example, sodium hydroxide, 1.0 normal, would be defined as follows:

"A water solution of sodium hydroxide, substantially free from carbonates. Each ml. at 25° C. contains 0.040 gram of sodium hydroxide and neutralizes 0.0010 gram of hydrogen ion to a phenolphthalein end point.

"From 0.9998 N to 1.0002 N is considered to be 1.0 Normal and used without other factor."

Stability

Mention necessity for fresh preparation, need for special containers and precautions needed to prevent change of standardization. Indicate usual time lapse under ordinary conditions, after which restandardization may be required.

Apparatus

List apparatus needed to prepare, analyze and correct the material. Mention balance sensitivities required and glassware calibrations, etc., as in "D" methods.

Reagents

List all reagents required both to prepare and to analyze the material. Be sure to indicate the grade of the raw material and give chemical formulas to indicate such factors as water of crystallization, etc. Refer to notes if the reagent requires special treatment not an integral part of the preparation, as for example, the several weeks settling of 50% sodium hydroxide.

Preparation

Begin by stating the amount of the preparation to be made. Give a precise statement of all of the steps to be taken.

Standardization

If none, so state. Otherwise, carry the standardization through stepwise in the same manner as given under "Procedure" in write-ups of "D" methods, including the calculation of normality, etc., and correcting to desired limits. Give numerical examples.

Notes

1. Use notes to give explanations, hints or precautions too long to include in the procedure without detracting from the flow of directions.

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Figure 2
Format for Preparation Methods

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FORMAT FOR EQUIPMENT METHODS

Function

A brief statement of purpose for which the instrument is designed.

Description

Describe physical appearance. Location of Controls. Placement of parts. Electrical circuits, etc.

Theory

Describe briefly and as simply as possible the theory upon which the functioning of the device depends. Refer to more thorough treatment in texts, etc., if need be.

Procedure

Describe the exact manner in which the device is to be operated normally. If logical, defer remarks concerning Calibration to that section.

Maintenance

Describe how to keep clean, prevent vibration, protect against corrosion, etc.

Adjustments

Describe methods of adjustment other than those required as a part of regular use or of calibration. These may be leveling, the degree of movement of levers, switches, etc.

Calibration

Describe exact procedures for calibration.

Notes

1. Use notes to give explanations, hints or precautions too long to include in the procedure without detracting from the flow of directions.

2. Omit sections which do not apply.

3. In some cases new sections may be required.

4. In general, the E-method format will be more flexible than the D or P ones.

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Figure 3
Format for Equipment Methods

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FORMAT FOR ANALYTICAL METHODS (Note 1)

<u>Epitome</u>

A brief description of the fundamentals of the method, together with definitions of such items as viscosity, heat stability, etc., which lack meaning if not defined.

Include chemical equations where feasible.

State basis of figures reported, i. e., "Results reported as % sulfuric acid by weight".

<u>Apparatus</u>

List all apparatus by name and size or kind
Balance, 4-place
Buret, 50-ml., calibrated
Graduate, 2-liter
Pipet, 10-ml.
Special absorption bulb (Note 2)

<u>Reagents</u>

0.1 N sodium hydroxide (P-xxx)
1 N sulfuric acid (P-xxx)
Dilute hydrochloric acid (P-xxx)
Somebody's reagent (must be freshly prepared). (P-xxx).

<u>Procedure</u>

Keep sentences short. Begin each with the verb denoting the action to be taken, where reasonable. Paragraph at logical points in the procedure.

Refer to notes (Note 3).

Indicate required accuracy of weighings and other measurements, as "Weigh approximately 2 grams to 0.001 gram".

Be complete and precise, so that exact following of directions will result in the analysis being properly performed.

Refer to E numbers for proper manipulation of instruments such as colorimeters, density balances, etc.

<u>Calculations</u>

Define symbols and show formula in full, followed by simplified formula, if any. Refer to changes in calculation constants if unusual samples may require them. Always include a numerical example. If no calculations, so state. Substitute "Interpretation" if the method requires it. A typical arrangement:

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Let: W = Weight of sample
T = Volume of 0.1 N sodium hydroxide used
(1 ml. = 0.0049 gram sulfuric acid)

Then: $\% \; H_2SO_4 = \frac{T\,(0.0049)\,(100)}{W} = 0.49T$

Numerical Example:

W = 2.017 grams
T = 42.3 ml.

$\% \; H_2SO_4 = \frac{0.49 \times 42.3}{2.017} = 10.3\%$

<u>Precision</u>

Standard deviation of replicates =

<u>Notes</u>

1. State first substance or quality to be determined followed by the material under examination. For example: "Sulfuric Acid in Commercial Sulfuric Acid" or "Ball Fall Viscosity of Viscose".

2. Use notes to describe apparatus, not sufficiently covered by name, or to give directions for making or conditioning same.

3. Use notes to give explanations, hints or precautions too long to include in the procedure without detracting from the flow of directions.

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D-000	2-9-48	2	WEH	WEH	J. W. Allquist

Figure 4. Format for Analytical Methods

Compare the results obtained by the two men using the following statistical technique. Compute the statistic

$$D = \frac{(\bar{x} - \bar{y})\sqrt{mn}}{\sigma\sqrt{n + m}}$$

where

$\bar{x}$ = average result obtained by the analyst on one sample;
$\bar{y}$ = average result obtained by the auditor on one sample;
m = number of replications contained in $\bar{x}$;
n = number of replications contained in $\bar{y}$;
σ = standard deviation of replicates for the method.

D will be recognized as being the difference between the averages of the analyst and auditor expressed in units which are the standard deviation of the distribution of the $(\bar{x} - \bar{y})$'s. Plot D on a control chart, using a center line of zero and limits of ± 3.

The charts will allow the sort of interpretation as other control charts. They can be plotted for each auditor, each analyst, and each method, or for any combination or breakdown that is meaningful.

One of our most troublesome tests was the determination of the ammonium chloride index of ripeness of the viscose solution. This solution is the one which is spun into rayon by precipitation in an acid bath. Its chemical and physical characteristics change with time, but the rate of change of ripeness can be controlled by temperature adjustment. The solution must be precipitated when its index is in certain prescribed limits. The test is a titration of a dilute solution of viscose with a standard ammonium chloride solution. The results are reported in milliliters of ammonium chloride for a specified weight of viscose solution. The end point is reached when the viscose solution thickens to a specified consistency, determined in a specified manner. In essence, judging the end point amounts to the analyst deciding whether or not the solution flows or drops off a glass stirring rod. When flow stops and dropping begins the end point has been reached (see Fig. 5).

Figure 5
Ammonium Chloride Index End Point

You can well imagine that this test would provide a splendid battle ground for production and control people. Indeed in times past it did, and the battles were of some consequence because when the ripeness index is out of specifications on the low side, discarding about $65 worth of viscose solution to the sewer is involved, not to mention upsetting schedules. Determining and publicizing the precision of the test, and a one-time demonstration that all analysts were performing in essentially the same manner had only a little effect on the propensity of the production people to complain about "wrong" results.

A combination of two things has now silenced complaints about the

analysts' work for more than a year. One thing was setting up and using a control chart for D, already described, comparing the analyst on duty with an auditor once each shift. The other thing was improvement in the control of the ripeness index accomplished by production people after a strong statement from management reaffirming its confidence in the ability of control charts, long since established, to describe the limits within which it was possible to maintain the index.

The ordinary control charts for production are also of great worth in controlling the laboratory. Their value in this respect should not be overlooked. Following is a description of an experience which illustrates this point.

To determine the concentration of cellulose acetate in acetonic dope (the mixture from which acetate yarn is spun by precipitation in hot air), a small amount (weighed by difference) of dope is squeezed out of a tooth paste tube onto a hot plate similar to a sandwich toaster. The flat cover is quickly lowered; the dope is thus dried for a predetermined length of time; when the cover is raised a small wafer of cellulose acetate is ready for immediate weighing. The set-up for doing this (see Fig. 6) includes two balances. The one on the right is specially fitted for weighing toothpaste tubes. The one on the left is specially fitted for weighing hot wafers. Each balance has a stool in front of it. In between the two balances is located one hot plate with four separately hinged covers. These analyses are run in duplicate at irregularly spaced intervals about four times per shift, three shifts per day, seven days per week. This work is confined to four analysts. Averages of the duplicate runs on individual samples and ranges of the duplicates are plotted on control charts.

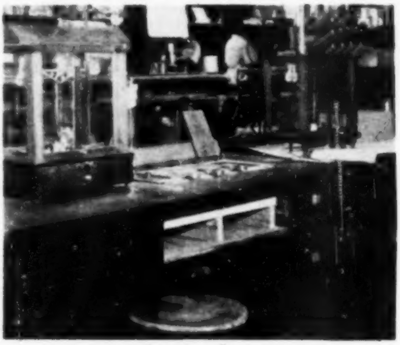

Figure 6
Set-up for C. A. Concentration in Dope Determination

It was noticed on the range charts that occasional points were falling out of limits. This could have been caused either by poor mixing of the dope or by errors in the analysis. In investigating, the charts were replotted, plotting one chart for each analyst. Analyst A's chart showed him to be biased toward the high side for both the range and the average. It was also noticed in recomputing and listing his range of duplicates that his first run was on the average higher than his second run. Statistical significance of this was demonstrated by the sign test. All four charts, coded to disguise names, were shown to the analysts, telling each one his own code name. The situation was explained to them and they were asked to help in finding the trouble.

They were not long in coming up with the answer. The hot plate had become warped in use, and wafers dried on the second position from the right were thicker than wafers from the other three positions. This extra thickness, by allowing some volatile matter to remain in the wafer, was enough to make determinations made on this position higher, on the average, than the other three. Now the two right-hand positions of the hot plate can be

reached while sitting at the right-hand balance, but the two left-hand positions cannot, and similarly for the left-hand balance, only the two left-hand positions can be reached while sitting in front of it. Thus one can sit while weighing and either place on or remove from the hot plate, but not both. If one chooses to sit while weighing and depositing dope onto the plates, he is forced to use the two right-hand positions. This is the habit that analyst A had fallen into. Analysts B, C, and D had adopted the other sitting and standing pattern. Thus almost invariably, unlike the others, analyst A's first run was made on the warped position of the hot plate, making it give a high result.

When the difficulty was discovered, the warped hot plate was replaced by another of a slightly different design, the new design being intended to prevent warping.

CONTROL OF THINGS

In addition to controlling the work of the technicians, the things they work with must also be controlled. Things sometimes seem to have a disaffection for people, and enjoy seeing them confounded. At any rate, things do change with time and use. These changes, of course, can and do affect the results of tests. For proper control, changes must be detected and corrected before they have gone too far.

In our plant the primary weight standard is a set of stainless steel analytical balance weights which are calibrated once each three years for us by the United States Bureau of Standards. Our secondary or working standard weights are the same type as the primary standard. They are checked at least every six months on our best balance. If they are off, they are adjusted to be correct to the nearest 0.05 milligram. The primary standards are never used for any purpose other than to check and correct the secondary standards. Other sets of weights are checked and corrected to the sensitivity of the balance on which they are used, using the working standards. The beam rider and chain of the balance are checked at the same time. Beam riders may be lowered in weight, but they are replaced if too low. Chains are always replaced if not correct. The frequency of checking weights other than the two standards varies according to their frequency of use and location, but a definite schedule is maintained.

While it is realized that there probably are other systems of controlling the accuracy of laboratory weights which are just as good, this system has proven itself to be satisfactory. It also has two very definite advantages. In routine determinations one does not have to make weight calibration corrections. And neither is it necessary to do all of the weighings for one determination on the same balance.

In the interest of speed and simplicity our standard solutions, as with our weights, are all adjusted to a specified tolerance according to the purpose for which they are to be used. The extra time it takes to do this we think is well repaid in time and errors saved in making corrections on results.

All laboratory instruments are checked on a regular schedule. The schedule for each instrument depends on its likelihood of losing adjustment. For example, serimeters are checked once each week; pipets used for caustic soda solutions are checked once each two months; and colorimeters are checked each time before use.

In a situation where more than one instrument is used for the same job and where no standard sample is available, control can be handled very nicely by a technique which I will illustrate by describing how we control our serimeters.

A serimeter is a machine used for breaking yarn in order to determine its strength and elongation. Among these machines in our laboratory are six of the pendulum type (see Fig. 7). All six are the same make, but not all are the same model. The problem is to adjust and maintain these machines in such a manner that they are interchangeable in use.

There was a time when work on one machine was not comparable with work on any of the others. Research begun on one machine had to be carried through to completion on the same machine, and each type of yarn was assigned to one particular machine for routine control testing. As can be imagined, this was a very inconvenient and sometimes very embarrassing situation. But the problem has been satisfactorily solved, and the machines are now interchangeable.

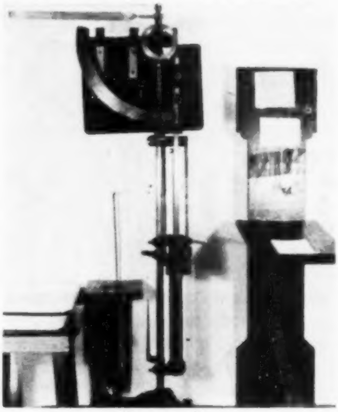

Figure 7
Pendulum Type Serimeter

Serimeters are checked each Friday morning. They are checked for speed of descent of the lower yarn clamp, distance between yarn clamps, level, and dead weight indication on the quadrant scale. If any of these characteristics are not within specified limits, proper adjustments are made to bring them back in.

It would seem that these checks and adjustments would be sufficient to insure that all machines would behave in essentially the same manner, but such is not the case. Even though two machines indicate the proper weight in a static condition, they may very well not give the same result when breaking yarn from the same source. Therefore, the machines are checked further by actually making tests on selected yarn, comparing the results by plotting on a control chart. The comparison is accomplished in the following manner.

One two-pound bobbin of dull acetate continuous filament yarn is selected for use. This is enough yarn to last for almost a year and a half of weekly checking. Using yarn from the same bobbin each week assures having yarn from the same source, but of course nothing can assure having the same yarn since once broken in testing it cannot be broken again. Worse still is the fact that yarn strength and elongation depend on the yarn's moisture content which in turn is dependent on the temperature and humidity of the surrounding atmosphere, plus the length of time it has been in that atmosphere, plus the direction in which the current atmospheric conditions are tending to change its moisture content. Even though the laboratory's atmosphere is held relatively constant, and even though the same bobbin of yarn is used, the yarn strength and elongation vary through the bobbin and over eighteen months more than can be explained by the variation in consecutive individual tests made in one short period of time.

Five determinations are made on each of the six machines. The averages and ranges for each machine for strength and elongation are plotted on the same control charts with the following limits. For the range chart, the center line is $K_1 \bar{\bar{X}}$, where $\bar{\bar{X}}$ is the grand average of all thirty determinations, and $K_1 = \sigma' / \bar{X}' d_2$, σ' and $\bar{X}'$ having been previously determined for the bobbin of yarn in use, each machine contributing equally to their determination; the limits are zero to $K_2 \bar{\bar{X}}$, where $K_2 = \sigma' D_2 / \bar{X}'$. For the average chart, the center line is $\bar{\bar{X}}$; the limits are $\pm K_3 \bar{\bar{X}}$, where $K_3 = A\sigma' / \bar{X}'$. The constants K_1, K_2, and K_3 need to be calculated only one time for each bobbin, but new center lines and limits must be calculated each time a comparison is made.

If a machine is out of limits, it is taken out of service and repaired. Before it is allowed to return to service, ten determinations are made on it and the range and average of these ten tests are required to fall within limits computed as those in the preceding paragraph except that $\bar{\bar{X}}$ is now taken to be the average of the remaining five machines, the constants D_2, A, and d_2 being changed to those for ten individuals instead of six as before. In this way we can be assured that all of our serimeters are performing in essentially the same manner. When one does fail we can single it out. And we can prevent its being returned to service, if it has not really been brought into agreement with the other machines.

SUMMARY

Control laboratories provide a service, but an analogy can be drawn between the results they report and the goods the factory produces. Both must satisfy and gain the confidence of the customer, in the laboratory's case the production division. The control division should practice what it preaches. It should supply results at the required quality level, that is, required accuracy, and with consistency, that is, in statistical control. Very much the same measures are required of the laboratory as are required of production. They are:

1. Clearly written instructions.
2. Scheduled checking of analysis and equipment.
3. Use of statistical techniques to detect assignable causes of variation in analytical and testing procedures.
4. Correction of equipment, analysts, or instructions when statistical analysis indicates the necessity.

While the quality control engineer's job is to help production make acceptable product for less money, let us not allow ourselves to be discovered in the position of the cobbler whose children were without shoes.

QUALITY CONTROL IN THE STAPLE YARN MANUFACTURING INDUSTRY

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During the past ten or twelve years testing and quality control have made tremendous strides in the staple yarn manufacturing segment of the textile industry. Prior to that time, a mill with an adequate, well-functioning quality control department was the exception rather than the rule.

With the beginning of World War II, the Armed Forces demanded almost unbelievable production rates from the textile industry as well as other industries, and at the same time demanded certain minimum requirements for the materials. This meant that a large portion of the textile industry found itself trying to meet specifications for the first time, and as a result, testing equipment was acquired, and the nucleus of a quality system was formed. With this as a beginning, the practice of quality control has continually expanded until there are more mills now participating in full, well-balanced control systems than ever before in the textile industry.

I do not wish to imply that the textile industry was not quality conscious prior to this period. To the contrary, some of the highest-quality yarns and fabrics were produced in the textile industry years before any industry-wide movement toward organized quality control departments. However, during the early years of the industry in this country, the production of high-quality material was more of an art than a science. With the advent of higher labor and manufacturing costs and keener competition, the industry was forced from the artistic approach to the scientific approach. This, coupled with the circumstances prevailing during the period from 1940 to 1946, brought about the circumstances now prevailing in the textile industry. Unfortunately, all of industry is not capitalizing upon the advantages of quality control. With a few exceptions, only the larger organizations have installed central quality control departments and given these departments the necessary authority required to realize the optimum results of the system.

The term "quality control" in the textile industry, in its most liberal definition, does not necessarily include the application of statistical analysis or control charts. However, this phase is also making rapid advances, but here again it appears for the most part only in the larger organizations. This is justifiable to some extent, since some of the smaller mills do not manufacture materials of such quality that demand this type of control. Nevertheless, there are still many large as well as small organizations which could profit by these applications if they were more familiar with the advantages to be gained by such methods.

The application of these techniques in the textile industry can be a rather complex and disheartening task. This can be attributed to such causes as: (1) the variability of the raw materials - the cotton fiber in the case of cotton yarns, (2) the infinite number of variables that can, and usually does, enter into the process of converting a bale of fibers into yarn and fabric form, and (3) the lack of actual control, in its strictest sense, over the individual fibers during processing. These are only three of the many difficulties encountered in yarn manufacturing which complicate the control of the finished product. Even though such problems exist, certain parts of the industry have made tremendous advances in the application of statistical quality control charts, and

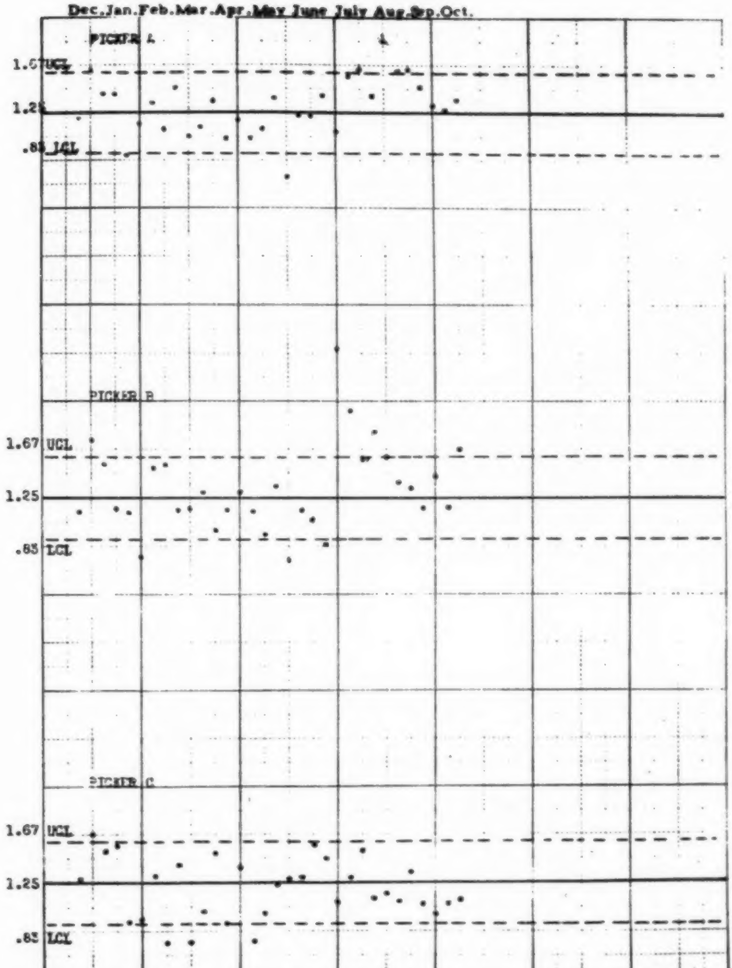
as examples of some of the applications, I have a few slides which I would like to show you.

The first slide shows a control chart which was kept on the first operation in a textile plant where it is important to control the size or weight of the material delivered from a machine. The quality being measured is the variation in weight of a picker lap. The term "picker" does not refer to the picking of cotton in the field but is the name of a machine designed to form the cotton fibers into a package or shape known as a lap. The lap is a continuous roll of fibers, usually 40 inches wide and 45 to 55 yards in length, and weighing from 12 to 16 ounces per yard. The lap is similar to a roll of sterilized cotton except, of course, it is much bigger. The control of the weight and evenness of this lap of fibers is very important to any yarn mill if it is to produce an even, high-quality yarn. This particular chart shows weight variation from yard to yard in the lap with the variation being expressed as coefficient of variation. To establish the coefficient of variation, a lap is placed on a machine which will automatically unwind the lap and weigh one-yard lengths. With this data, the coefficient of variation is calculated. The center lines and control limits in this case were based upon a given standard of 1.25 percent variation. This particular organization had found from past experience that a coefficient of variation for this process of 1.00% was excellent, 1.00 to 1.50 was good, 1.50 to 1.75 was fair, and 1.75 and over was poor. Based on these findings, it was decided to use 1.25 percent as a given standard for establishing control limits. The limits were calculated using the relationship

$$C.L._V = V^1 \pm \frac{3V^1}{\sqrt{2n}}$$

As can be seen, pickers A and B were in a state of control until the latter part of August. The four points out of control were found to be caused by cotton from the new crop which reached the mill at that time.

Once this process was brought into a state of control, the quality control department focused its attention on the drawing process, another key point in yarn manufacturing, and with these two steps in a state of control, the company shipped to one customer, which had a very rigid specification, well over one and one-quarter million pounds of yarn without any rejects and with only two minor changes in the mill during that particular period.



The next set of slides is an excellent example of the benefits derived from this type of control system when installed and maintained from raw material to finished fabric, and if sufficient thought is given to the problems encountered and the proper applications made of the available techniques. All of these charts are from the same company, and you will see as we progress with the slides the degree of control under which they operate.

CHART XV

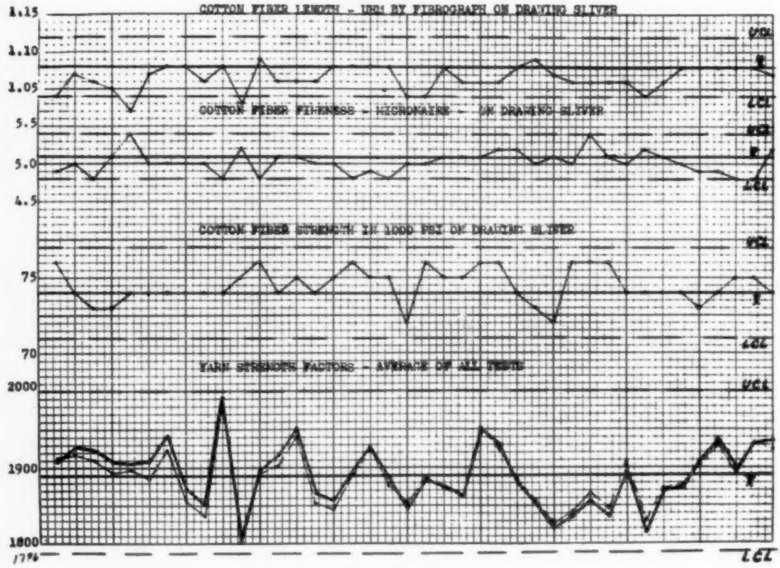


Figure 2 shows the fiber properties of some of the cotton used in this mill and the yarn strength factors for singles yarn produced. You will remember that I mentioned earlier the lack of actual control the textile industry can maintain over the raw material. This is shown in the top chart; as you can see, the fiber length is out of control at two points at the left-hand side of the chart. The second chart shows the fiber fineness, or weight in micrograms per inch of fiber, to be in a state of control, as well as the fiber strength and the yarn strength factor, as shown in the third and fourth charts.

This means that the raw material is not varying beyond reasonable limits. You will notice that the fibers are already being processed since they are in drawing sliver form. This will help to explain the uniformity of the fiber properties, since the cotton from several bales is well blended by the time it reaches this stage in the process; and also the fact that the fibers have been carded helps to explain some of the uniformity.

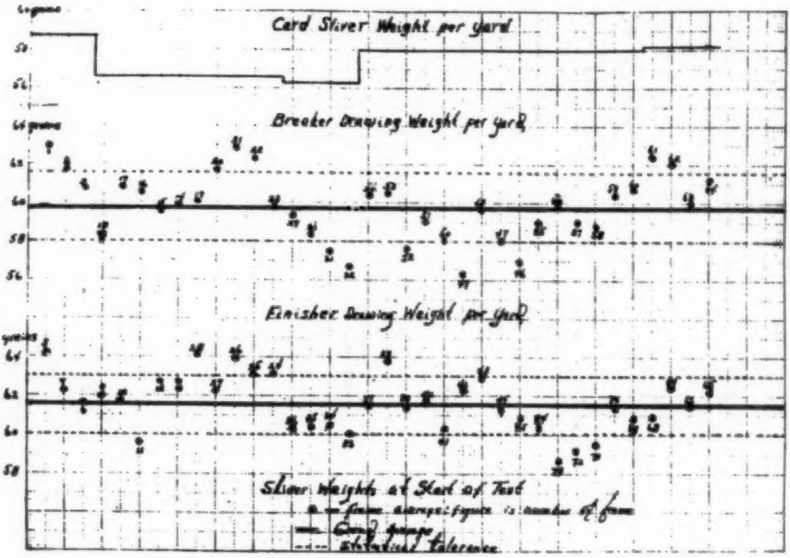
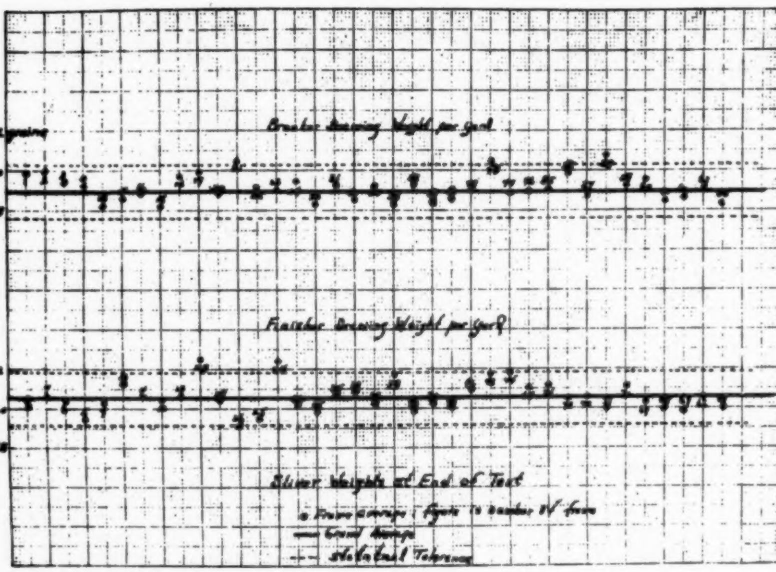


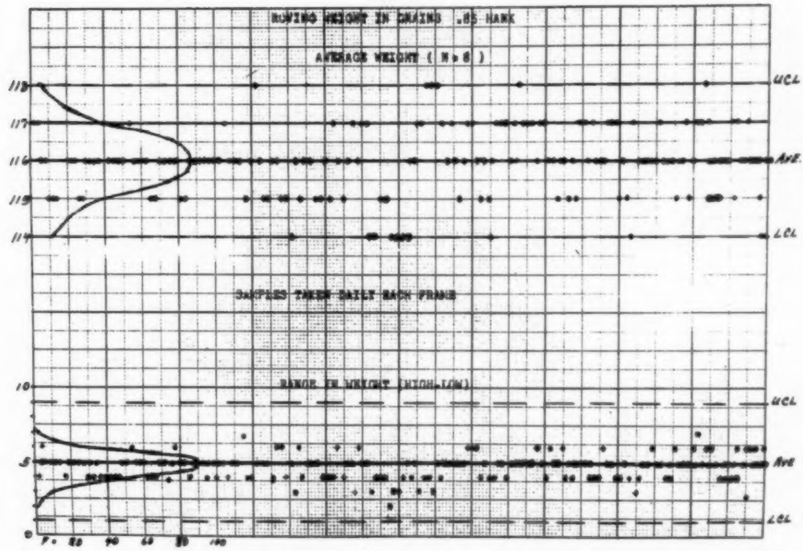
Figure 3 is what the quality control department of this mill found at the drawing process when the investigation of this process was begun. Please notice the absolute lack of control of both the breaker and finisher drawing processes. Keep this picture in mind as we look at the next figure.



This is the picture after all the machines were overhauled and adjusted to the same settings, sizes of parts and gears. By the strictest definition, you will notice a few points out of control, but in the textile industry, if you can operate so that only 20 to 25 points out of every 1,000 are out of control, that is considered satisfactory.

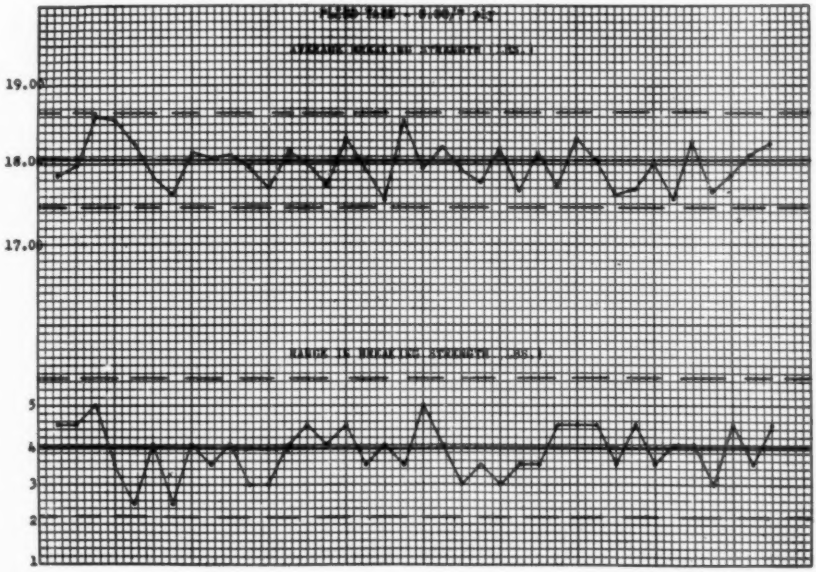
The next step in the manufacture of yarn is the reduction in size of the drawing sliver into what is known as roving. This is the last step prior to the spinning of the yarn, and Figure 5 shows the degree of control this mill has over this process. As you can see, this process is in a perfect state of statistical control.

CHART XIV



The next figure shows the results of all the previous figures. As you can see, both the average breaking strength of the yarn and the range in breaking strengths are well under control as the material approaches the final process of weaving. (Show Figure 6.)

CHART XVI



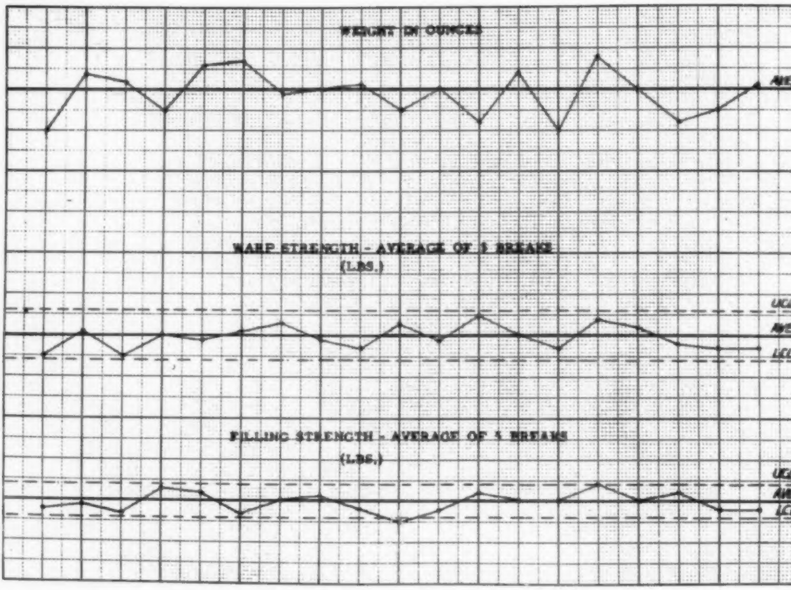
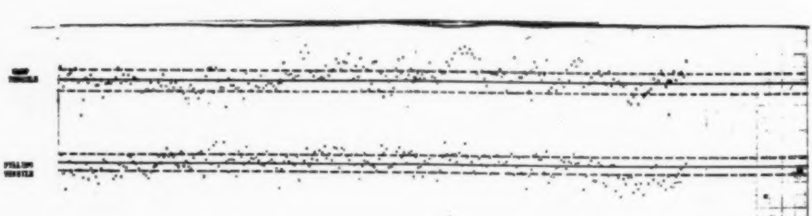


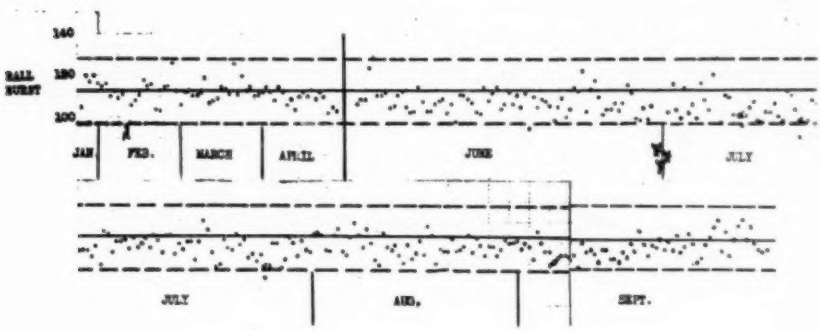
Figure 7 shows the ultimate goal: fabric control with respect to strength. I have intentionally omitted the strength values so as not to identify the company, since they have requested to remain anonymous; however, I can assure you that all of these charts are authentic and actually came from the files of one of our largest manufacturers.

Just for comparison, I would like to show you a chart made on exactly the same type of material but manufactured in a plant that did not use any form of statistical control. (Show Figure 8.)



The complete lack of control is obvious.

I have shown you how the industry is using quality control during manufacturing, and as my last example, I would like to show you one very interesting application of consumer use of statistical control. (Show Figure 9.)



This chart is for the bursting strength of a knit fabric, and one of the requirements of the end product in which this fabric was used was a high bursting strength, so as a result, that was the factor of prime importance in the fabric.

When the chart was first started, the bursting strength was well under control, but you will notice that there was soon a shift in strength to the low side of the chart. This shift occurred during the month of April at the vertical line. At this point, a conference was held between the supplier and customer. As a result of this conference, it was found that the supplier was also maintaining a chart on this fabric and that the center line and control limits were identical on both the supplier's and consumer's charts, even though neither knew that the other had a chart. That was all that resulted from this conference, and when the strength failed to improve, the fabric that fell out of control was rejected and another conference resulted. At the second conference, it was found that the production of this material had been moved at the time of the quality change from a Northern plant to a Southern plant. The finishing of the fabric was quite important, and the supervisor of the Southern plant was not familiar with the proper finishing methods for this particular fabric; thus, the loss in strength. As the supervisor of the new plant became more familiar with the fabric and improved their finishing methods, the strength increased, as you will notice at the ends of the chart. I am thoroughly convinced that this change would have gone unnoticed had it not been for this control chart, and there is no accurate way of estimating the thousands of dollars this one chart saved the company.

I trust that I have given you some idea of the progress being made in quality control in the textile industry. There are still plenty of prob-

lems to be solved with respect to quality control and testing. More and better testing equipment is badly needed, and better processing equipment is also needed. These problems are being solved, and the industry is profiting and will continue to profit by the work that is being done in these fields.

In the School of Textiles at North Carolina State College, we are impressing upon our graduates the value of and the benefits to be derived from a well-functioning quality control system. Included in this training are courses pertaining to proper test methods and instruments, analysis of data, and some of the causes of poor quality. Some of the graduates are now in positions with mills where they are supervising and installing quality control systems. With the industry being supplied men of such caliber and training, it will mean that more and more of this type of work will be done.

It is true that some sections of the industry have been slow in the past in accepting new ideas and methods, but even so, I personally am proud to be associated with the textile industry; and, with the help of such organizations as this, we will continue to move forward and take our place among the highly scientific industries.